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ELEMENTS

OF

PHYSICS.

BY

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ETC.

TRANSLATED FROM THE GERMAN,
WITH NOTES,
BY E. WEST.

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CONTENTS

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IMPONDERABLE BODIES—*continued.*

PART II.

SECTION IV.

ELECTRICITY - - - - - - - § 464—544
I. Electrical Phenomena in general - - - - - 464—478
II. Frictional Electricity - - - - - - 479—500
  Fundamental Effects and Phenomena of Frictional Electricity - - - - - - - 479—483
  The Electrical Machine, its Mode of Action and Uses - - - - - - - - 484—485
  The different Kinds of Apparatus which act by the Induction of Electricity - - - - - 486—490
  The principal Pieces of Apparatus used with an Electrical Machine for the performance of Experiments - . . - - - - 491—500
III. Electricity by Contact, Galvanism, Voltaism - - 501—523
  Electricity elicited by the contact of Heterogeneous Bodies in general - - - - - - 501—504
  Different Kinds of Hydro-electric Batteries - 505—508
  Voltaic Piles in an Electro-statical and in an Electro-dynamical Condition - - - - - 509—511
  Different Effects ot Hydro-electric Currents - 512—523
IV. Electrical Phenomena resulting from the Chemical Action that attends the Change in the Aggregate Form of Bodies, those which result from their separation by Mechanical Means, and those which are caused by the Compression of Bodies - - - - - - - - 524—526
V. Electricity generated by Heat, Light, and Magnetism - 527—535
VI. Atmospheric Electricity, and the Electrical Phenomena of Life - - - - - - - - 536—544

SECTION V.

Electro-dynamics, or the Phenomena of Electro-magnetism and Magneto-electricity - - - - - § 545—585
I. Electro-magnetism - - - - - - - - 546—549
  Influence of the Electric Current on Magnets suspended freely - - - - - - 546—547

Influence of Electric Currents on each other - § 548—554
Influence of Magnets on Electric Currents - - 555—559
Influence of Terrestrial Magnetism on Electric Currents - - - - - - - - 560—565
Excitation of Magnetism by Electric Currents - 566—570
II. Magneto-electricity, or the Inductive Influence of Electric Currents - - - - - - - - 571—585
Electric Currents excited by Means of others - 571—574
Electric Currents generated by Magnets - - 575—585

ELEMENTS

OF THE

PHYSICS OF IMPONDERABLE BODIES.

PART II.

ELECTRICITY, ELECTRO-MAGNETISM, AND MAGNETO-ELECTRICITY.

SECTION IV.

ELECTRICITY.

I. ELECTRICAL PHENOMENA IN GENERAL.

§ 464.

Electricity is the etherial power which affects all our senses, and which produces the most varied results in its influence on all bodies whatever; it is diffused thoughout the globe, and resides in all terrestrial substances. As yet, it has not been ascertained whether its presence is confined to our planet, or whether it exists thoughout the universe.

Its presence is generally not perceptible in bodies, which are then said to be in a state of *electrical quiescence.* It is not, however, to be considered as certain, that electricity in this condition exerts absolutely no influence at all.

§ 465.

Electricity becomes sensible when this state of quiescence is disturbed, and the electricity is set *free.* Probably no change transpires in the material world which is not connected more or less intimately with a disturbance of this condition of repose, and an excitement of the electric power to a state of activity. The principal causes of electrical excitement with which we are at present acquainted, are the *friction* and *contact* of heterogeneous substances, *change of temperature*, the *vital process*, the *functions of the atmosphere*, the *pressure* and *rupture* of bodies, and *magnetism*. Philosophers are not unanimous as to whether *chemical action* and a *change in the aggregate form of matter* are capable of exciting electricity. The ordinary means of excitation employed are *friction*, *contact*, *heat*, and *magnetism*. According to the source from which it is derived, it is called *friction electricity*, *electricity by contact*, *thermo-electricity*, *and magneto-electricity*.

Faraday has demonstrated, that the electricity liberated by these varions modes is essentially the same; that the source whence it is derived affects its operations mainly in this respect, that one method will give us a small quantity of electricity of great intensity, whilst another will yield a larger amount of electricity, but of less intensity.

§ 466.

Bodies in a state of electrical activity are said to be *electrified*. The different phenomena which they display may be ranged under the following heads:

1.) *Mechanical phenomena*, which are observable in the motions, or even in the disruption of other bodies.

2.) *Luminous phenomena*, which are attended with a report more or less loud.

3.) *Thermal phenomena*, such as the incandescence, fusion, and combustion of bodies.

4.) *Chemical* effects, consisting of the chemical combination and resolution of bodies.

5.) *Physiological phenomena*, such as the production of a peculiar phosphoric odour, a sensation as if fine spider's webs were drawn across the face, an affection of the nerves of sight and taste; and lastly, a convulsive action of the whole nervous system, sometimes slight, at others more intense, and occasionally even mortal.

6.) *Magnetic phenomena*, affecting magnetic bodies, and imparting magnetic properties to non-magnetic substances.

The various exhibitions of this electrical power do not all occur simultaneously, or with equal degrees of intensity: in many cases they are so feebly developed that instruments are required to collect and render visible the effects produced. For this reason, it was formerly thought that only certain substances possessed electrieal properties; with many of the phenomena of electricity we have become acquainted only within a comparatively short period.

§ 467.

The electrical state of any body, whatever may be the cause which has induced that state, is estimated by the *quantity* and the *intensity* of the electricity which has been called forth into action. The electricity liberated may be measured, and its quantity may be expressed by means of any electrical effect that is assumed as the unit of measurement. Its density depends on its quantity, and on the extent of the surface over which it is spread. If the quantities of electricity be equal, their densities will be inversely as their surfaces; *i.e.* if one surface be n times larger than another, then the density of the same quantity of electricity will be $\frac{1}{n}$th of that on the lesser surface.

§ 468.

The electrical state of a body may be merely *temporary*, *i.e.* an electrified body may, after the lapse of a longer or shorter period, lose its electricity, and resume its condition of electrical quiescence, when it will be said to have *discharged* itself. The time required for this purpose depends on the nature of the bodies in contact with the surface of the electrified body, and their readiness for acquiring its free electricity. All substances possess the property of withdrawing the free electricity from any body with which they may be in contact, and appropriating it to themselves; when this is accomplished, they are said to be *electrified by conduction*. According to the time consumed in this process bodies are divided into *conductors*, *non-conductors*, and *bad conductors*. The loss of electricity sustained by any electrical body may thus be measured: the means by which this is effected we shall explain presently.

Conductors are such bodies as become electrical instantaneously through their whole extent, when the electricity is imparted to them at any point of their surface; they also part as quickly with the electricity they have acquired, if one end be connected by means of a second conductor with the earth. Their characteristic property consequently is, that *electricity may be readily excited in them, and that when excited it is freely propagated.*

The *non-conductors* are substances which possess properties the very reverse of those just described; *i.e.* they carry off free electricity but slowly when touched by an electrified body, or if their condition of electrical indifference is disturbed at any one point, they become electrical at that point only; and if their whole surface be excited, and they are then touched by some conductor connected with the ground, they part with their free electricity only at the point of contact. Their characteristic is, that *they retain free electricity for a length of time, and that they check its motion.*

Hence good conductors can be electrified only when the free electricity they contain has no opportunity of escaping to the earth. To effect this we cut off their connection with it by supporting them on some non-conducting substance: when thus situated they are said to be insulated.

> It was formerly thought that none but the non-conductors could be electrically excited, and that no other bodies possessed electricity; hence the name of *electrics* given to the former, and *non-electrics* to the latter class of substances.

Between these two extremes there is a large class of *indifferent conductors*, the time required by which for the transmission of electricity is so considerable as to admit of its being easily measured. A strongly defined line cannot be drawn between these three classes of bodies; neither does there exist any such thing as a perfect conductor, or a perfect non-conductor; but the conductors, arranged in the order of their conducting powers, descend gradually to non-conductors.

Experiment and observation have shown that free electricity attaches itself variously to these bodies; that in the conductors it is accumulated only at the surface; but in substances of low conducting power, when subjected to powerful electrical influences, it penetrates to the interior, and is firmly retained.

§ 469.

Our earth is the universal conductor to which all the free electricity from other bodies tends to return. The principal conductors are those metals which have a regular structure; then well burnt charcoal and graphite (black-lead); next the earths; then most of the salts and many liquids, both in a fluid and vaporous form. Among the liquids, the acids are distinguished for their conducting powers; next come the aqueous solutions of the acids and salts; and last of all water itself. All other solid bodies become conductors when moistened or damp; hence all animals and vegetables are conductors. Lastly, flame, smoke, and vacant space are conductors.

On observing the list just given of the best conductors of electricity, it will be perceived that many of them, especially among the solids, are also good conductors of heat.

§ 470.

Among the *non-conductors* are to be reckoned all kinds of glass, the precious stones, particularly the diamond, the metalloids, especially sulphur, all the metallic oxides, and the alkalies and earths, when perfectly dry; the combustible minerals, with scarcely an exception; to this class, too, belong all kinds of hair, indian-rubber, wax, dry vegetable products, as sugar, gum, dry wood, cotton, &c.; the fatty oils, æther; all animal coverings, as hair, skin, feathers, the webs of spiders and caterpillars, silk, raw and spun; ice, in proportion to its coolness; all dry gasses, in proportion to their density; and lastly, perfectly gaseous steam.

Of the different non-conducting substances enumerated above, shell-lac is the one which insulates most completely; but glass is the body most generally used. The atmosphere is the most widely extended, and the most important non-conductor. Had the air been a conductor, the phenomena of electricity would not have been visible to us. It is worth noting, that its conducting power increases in proportion to its rarity and the quantity of aqueous vapour it contains.

The principal substances of *mean conducting power* are paper, parchment, wood, horn, bones, ivory, marble, alabaster, and several other stones, when situated in the open air, and in their ordinary state of dryness.

§ 471.

The *conducting power* of bodies, or the readiness with which, in a given time, they transmit through their mass a certain quantity of free electricity, is an important element in the results brought about by this agent. It varies not only with the substance of a body, but also according to its dimensions and temperature. It may be remarked generally, that silver and copper, among the metals, have the highest conducting power, whilst lead and quicksilver have the lowest; that among liquids the highest rank is filled by nitric and sulphuric acids, and the lowest by water and alcohol; further, that the conducting power of all bodies is weakened by increasing their length; that its intensity is increased by enlarging their transverse dimensions; lastly, the conducting power of metals is weakened by raising their temperature, but that it is increased by heating all other bodies, and especially liquids; nay, even some substances which are non-conductors in the solid form, acquire a very considerable conducting power when fused or melted.

> Thus Sir H. Davy found that glass raised to a red-heat, melted sealing-wax, pitch, amber, shell-lac, sulphur and wax became good conductors.

From the difference in the conducting powers of bodies arises the difference in the resistance offered to the conduction of electricity; or, as Riess terms it, the *electrical retarding force.* It diminishes the electrical influence in the same proportion as the propagation of the free electricity is retarded; and according to experiments made to determine this matter, this resistance and loss of power are inversely as the conducting power. The different intensity of certain electrical effects, measured by some standard unit, gives us the means of expressing, in numerical values, the conducting power and the resistance offered in different bodies. The manner in which this is done will be explained presently.

§ 472.

Most philosophers have assumed the existence of a peculiar *electrical fluid* as the cause of the various electrical phenomena which present themselves to our notice. In more fully explaining the properties of this fluid, there are two principal theories propounded, the one supposing that there is but *one*, the other that there are *two electrical fluids*.

The first of these hypotheses was proposed and defended by Œpinus and Franklin; the latter by Symmer. The greater number of electrical phenomena may be satisfactorily explained by either theory; the second has, however, been embraced by the greatest number of electricians: by it we shall explain the different electrical phenomena.

According to Franklin's view, the particles of this electric fluid are repulsive to each other, but are attracted by all bodies, and when combined with them, they lose their repulsive tendency towards one another. All terrestrial bodies contain this matter, but their capacity for it varies; when any substance contains that quantity which answers to its capacity, no electrical action is observed, and the body is in a state of *electrical indifference;* but if the fluid be in either redundancy or deficiency, this quiescence is disturbed and the body is electrified. When the fluid is in excess, the body is said to be *positively* electrified; when it is deficient, it is *negatively* electrified. A body may therefore be electrified, either by adding to its electricity, or by subtracting from it; or lastly, by the fluid, which was previously distributed equally throughout it, being accumulated in one direction, so that a redundancy is created in one part, whilst a deficiency exists in the other. Bodies positively electrified have a tendency to give out to other bodies the excess of their electricity; those which are negatively electrified endeavour to withdraw the fluid from others, to supply their deficiency.

If this view be adopted, the operations of electricity will be found closely to resemble those of heat.

According to the other hypothesis, all electrical phenomena result from the action of two electrical fluids diffused throughout the universe. These fluids are assumed to be extremely rare, imponderable, and expansive in the highest degree. The particles of each, by virtue of this last-named property, mutually repel each other, and in this respect the two fluids are perfectly equal. The particles of the one fluid are, however, supposed to have an attraction for those of the other; they therefore combine when no obstacle stands in the way, and when united in exactly equal quantities, they lose their expansive force. To one of these fluids has been given the appellation of *positive electricity*, + E; to the other that of *negative*, — E: they are both *antagonist electricities*, and this opposition is termed their *polarity*. If both the fluids exist in equal proportions in any body, no electrical action happens; but the body is in a state of *quiescence*, which is expressed symbolically, thus ± E, or 0 E. A body is *positively electrified*, either by imparting to it some free + E, or its condition of indifference is disturbed by withdrawing from it a portion of its — E; it is *negatively* electrified if the converse happen. A body may appear electrical on two opposite sides; for one may have positive and the other negative electricity. This electrical state obtains, if a portion of its neutral electricity be resolved, so that the positive electricity is accumulated at one extremity, and the negative at the other. If the cause ceases which excites this disturbance the fluids again combine, and the body is restored to a state of quiescence. Lastly, according to this view, all electrical phenomena are owing to the tendency of these antagonist fluids to combine in equal quantities, and in the property of their particles, mutually to repel each other and neutralize each other's effects.

Whatever may be the cause of the various electrical phenomena, we must regard our earth as an inexhaustible storehouse of electricity. It is in a manner a great reservoir, from which the fluid issues, or may be procured in various quantities, and to which it again returns from electrical bodies on its surface.

§ 473.

The states in which the free electrical fluid exerts its force are two; namely, the state of equilibrium, known as the *electrical tension*, and that of motion, when the two antagonist forces are in the act of combining; this is called the *electrical current*. From the former state the primary, and from the latter the secondary, effects of the electrical force derive their origin.

§ 474.

The electrical tension consists in the tendency of the free positive and negative electricities to regain their state of quiescence by combination each with its antagonist. This tendency is the more forcible the greater the intensity of the free electricity. (§ 467.) The fundamental effect produced by this tendency is the attraction of all such bodies as, by parting with their own electricity, would contribute to restore the state of equilibrium. Hence electrified bodies attract all other non-electrified bodies, and endeavour to saturate themselves with their opposite electricity. If the attracted body does not possess the requisite quantity of the fluid to saturate the attracting body, then the overplus of the free electricity is imparted to it, so that both bodies display an equal tension, and the body just now attracted is repelled. For similar reasons, every electrified body attracts to itself all oppositely electrified bodies. If they both contain equal quantities of opposite electricities, they saturate each other on contact being established, and both acquire a state of electrical indifference. If the quantities of the antagonist fluids are unequal, the bodies continue electrified after contact, and they both contain the electricity of that body, which, before contact, contained the largest amount of electricity. All similarly electrified bodies will repel each other, because the particles of the like electrical fluids exert a repulsive force against each other.

From a consideration of these phenomena, the following law of electrical attraction or polarity has been deduced: — *Like electricities* (+E and +E, and −E and −E) *repel each other; but unlike* (+E and −E) *attract; and if the quantities of dissimilar electricities be exactly equal, they neutralise each other;* that is to say, *they bring about the state of electrical indifference* (0 E). This law of electrical polarity bears a striking resemblance to that of magnetic polarity. (See § 437.)

The state of electrical tension may also be recognised by certain physiological effects, viz. a peculiar phosphoric odour, and a sensation as if spiders' webs were being drawn across the face.

§ 475.

The principal effect of tension, viz. attraction, is exerted in a radiant direction from an electrified point or ball, and its intensity decreases with the distance. By means of an apparatus, the construction and use of which we shall describe hereafter, Coulomb found that the law of forces acting from a centre was confirmed in this case, and that the intensity of these polar forces decreased as the square of the distance increased, *i. e.* at double the distance the intensity would be one-fourth; at three times the distance, one-ninth; at n times the distance, $\frac{1}{n^2}$ of what it is at the unit of distance.

§ 476.

The state of tension becomes converted into one of motion, or an *electrical current* is generated, if an opportunity is presented to an electrified body of combining with its antagonist electricity. This condition is fulfilled by establishing an immediate contact between the former body and one oppositely electrified; or, by connecting the two by means of a conductor; or, by connecting one of them with the earth. Under any of the arrangements just named, the dissimilar fluids rush together and neutralize each other on the passage offered them by the conducting medium. If two courses are presented to the fluid by which it may make its exit, it will select that where it meets with the least resistance, and if the conductors be equally good it will select the shorter.

The time that a current of electricity will last, depends on the retarding power of the conductor, and on the quantity of the fluid to be discharged; if this be but small, and the cause which induced the state of tension be merely temporary, the duration of the current is not appreciable in a good conductor, and the current is said to be *momentary* or *instantaneous;* if, on the contrary, the cause by which the tension is brought about continue for some time in operation, the current will be maintained so long as free electricity is generated and the current is said to be *permanent.* The momentary current is generally excited by frictional electricity, and the permanent by electricity by contact, by thermo-electricity, and by magneto-electricity.

The effects produced by a current of electricity are various. A momentary current, from a high degree of electrical tension, generally displays itself in intense luminous phenomena; in the disruption, combustion, incandescence, and fusion of bodies; in the violent convulsions of the nerves. It also produces feeble chemical and magnetic influences. A permanent electrical current, on the contrary, is marked by its powerful chemical influence, by an intense and permanent excitation of heat, and lastly, by its magnetic properties. The permanent electrical current exerts a less intense luminous influence, and acts slightly on the nervous system.

The explanation given above is based on the theory of two fluids which are supposed to move towards each other. According to Franklin's hypothesis, it is only the positive electricity, or the excess of the fluid in the two bodies, which is in a state of motion. This excess he supposes to go over into the negative body, *i.e.* into the body which has less than the normal quantity of electricity.

§ 477.

The velocity with which a current of electricity travels is greater even than that of light itself. Wheatstone, in an experiment, which will be described hereafter, estimated it at 288,000 miles, being half as great again as that of light. This is the rate at which it travels in copper wire, whether its velocity is as great in other conducting bodies has not yet been ascertained.

§ 478.

Electrified bodies also effect a resolution of the neutral electricity in unelectrified bodies into its elements (+ E and − E), when the latter are brought into proximity to the former. The distance at which the body originally electrified exerts this influence is termed its *electrical atmosphere*. This electrical excitement varies as the exciting body is in a state of tension, or is emitting a current of electricity. In the former case, bodies brought within the sphere of its influence are themselves put into a state of tension; in the latter, they discharge their electricity in a stream. The unelectrified bodies thus put into a state of electrical activity recover their original quiescence as soon as they are removed beyond the atmosphere of the exciting body. The electricity thus excited is said to be *induced*, and the process is called electrifying by *induction*. The special phenomena exhibited by induced electricity will be noticed in the course of this section.

II. FRICTIONAL ELECTRICITY.

A. *Fundamental Effects and Phenomena of Frictional Electricity.*

§ 479.

When two dissimilar substances are rubbed together, they are both brought into a state of electrical tension, conductors becoming electrified throughout their entire surface if insulated, non-conductors becoming so only at the parts subjected to friction. If one of the bodies be a non-conductor and the other a conductor, and the latter be connected with the ground, the former will be rendered susceptible of a more powerful tension. The electrical condition of these bodies may be most readily recognized by their attracting and repelling unelectrified bodies. A faint luminous appearance will also be visible, and the physiological phenomena described above (§ 474.) will be observable, but in a low degree. The following experiments will illustrate these phenomena.

First Expt. Rub a glass rod, or a stick of sealing-wax, with a woollen cloth, or with a piece of silk a few times, and you will observe: —

1.) Both the non-conductors which have been rubbed attract small pieces of paper, feathers, or similar light substances, and then repel them. The same may be seen by suspending a pith ball by a silk thread and presenting it to the electrified body.

2.) If the knuckle of your hand, or a small brass knob, be offered to the surface of the bodies you have rubbed, a snap will be heard, and if the room be darkened a small spark will be visible.

3.) If the glass rod be large enough a sensation will be felt as if spiders' webs were drawn across your face on bringing the rod before your eyes.

4.) Place the glass rod under your nose, and you will perceive a faint smell like phosphorus.

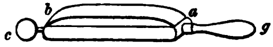
As the substances named in this experiment are non-conductors, these effects will be perceptible for some time, even though they may be touched in several parts of their surface. (§ 468.)

Second Expt. Hold a metal rod in your hand and rub it in like manner; none of these phenomena will be produced by it. The metal when grasped by the hand is not insulated, the electricity elicited is conveyed by the body of the operator to the ground. (§ 468.) The same remark holds good with regard to any other conductor; for which reason, these substances were long considered non-electrics.

But if a metal rod or plate be insulated, by fixing a glass handle on it, friction will render it electrical; if any point of its surface be touched, it will at once part with its free electricity, because of its conducting properties. (§ 468.)

Third Expt. To prove that both the bodies are electrified by rubbing them together, we must next offer some extremely light substance to the cloth or silk with which the rod of glass or sealing-wax has been rubbed; even then, perhaps, its electrical properties may not be evident. To verify the existence and to measure the intensity of these we must use some one of the delicate electroscopes which will be described in the succeeding paragraphs, or else the rubber must be so arranged that the electricity set free by the friction may accumulate itself on a conductor. *Fig.* 149. repre-

Fig. 149.



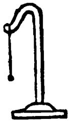
sents an apparatus contrived for this purpose. It consists of a piece of wood, in shape somewhat resembling a bat; on one side of which, *a b*, some strips of cloth are fastened. This is then covered with a piece of tinfoil of equal length and breadth, over which is placed a piece of soft calf's skin or linen, coated with some of the amalgam described in § 482, and then a piece of silk is strained over the whole. At one end of the rubber is placed a metal knob *c*, connected with the tinfoil, and intended to receive the electricity set free in the rubber; at the other end is a glass handle *g*, by which the instrument is held. If the cushion be rubbed with a glass rod, the knob *c* will immediately be electrified.

The attractive and repulsive properties of amber, ἐλεκτρον, when excited by friction, were discovered at a very remote period, and for a long while this was all that was known concerning the nature of electricity. It was not till the year 1600 that the same peculiarity was observed in other bodies, and for more than another century the science of electricity thus remained in a state of infancy. In the course of the 18th century it was gradually elevated by several men of science to an important rank in physics; but the most rapid advances have been made during the present century, and indeed during the last ten or twelve years of it. Since the discovery of electro-magnetism the most distinguished philosophers have laboured to carry out these recent discoveries, and to place on a firm and scientific basis a theory by which the varied phenomena of electricity may be satisfactorily accounted for; the completion of this object still remains to be accomplished.

§ 480.

Very often the electrical tension excited in a body is of so feeble a character, that its existence is not indicated by any of the effects yet described. In such cases we are compelled to have recourse to a class of instruments called *electroscopes*, or *electrometers*. The former merely show when a body is in a state of electrical tension, and what species of free electricity it possesses, whether positive or negative; the latter enables us to measure the intensity of the tension. They act in obedience to the universal law of electrical polarity (§ 474.), their most essential part being some good conductor, which moves very readily as it is attracted and repelled. They may be divided into the following classes according to the mode of their construction: — 1.) electroscopes in which only one moveable, light, and insulated conductor is first attracted and then repelled; 2.) electroscopes in which two such conductors repel each other after they have been impregnated with the electricity of the body under investigation; 3.) those in which only one of the conductors moves as it is attracted and repelled by the fixed one; 4.) those in which a moveable insulated conductor is placed between a positively and a negatively electrified body, so that when it has acquired the electricity of the body under examination, it will be attracted by that which is dissimilarly electrified. In all those instruments which are intended to serve as electrometers there must be a scale on which to measure the repulsion and attraction of the conducting body that acts as an index of the electrical tension, and by which we may be enabled to calculate the intensity.

Fig. 150.



The electroscopes of the first class in most common use are the following:— The *electrical pendulum* (*fig.* 150.) consists of a small pith ball, suspended by a silk thread. This is a very simple, but not a very sensitive apparatus. *Haüy's electrical needle* (*fig.* 151.) is very much like a common variation needle balanced on a point; at one end of the needle a small pith ball is fixed, that portion of it which carries the ball being of glass, whilst the other half, which serves as an equipoise, may be made of copper. This apparatus is much more sensitive than the other, and is well adapted to show the fundamental effect of attraction and repulsion.

The following instruments belong to the second class of electroscopes, and admit of being used as electrometers.

Fig. 151.

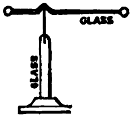
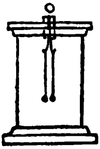


Fig. 152.

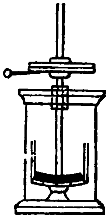


Cavallo's cork or pith-ball electrometer consists of two balls of cork or pith fastened to two very fine wires, which are attached to a conductor that conveys the electricity to them. (See *fig*. 152.)

Volta's straw electrometer is exactly like the preceding, only that fine straws are substituted for the wires employed in Cavallo's electrometer.

Bennett's gold-leaf electrometer is similarly constructed, but the pendulums are in this case made of two fine strips, about two lines in width, of gold leaf. (See *fig.* 153.)

Fig. 153.

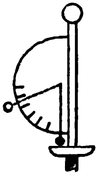


To protect the pendulums of all these electrometers from currents of air, they are enclosed in glass cylinders, through the lids of which the conductor that they are fastened to passes; by this means the conductor is insulated. To measure the degree of repulsion that obtains between the pendulums, a graduated scale is attached, as is shown in *fig.* 153. We may observe, that of the three electrometers last named, the first is the least sensitive; the last is so delicate as to mark very low degrees of electrical tension.

To the third class belong, among others, *Henley's quadrant electrometer*, *Brande's straw electrometer*, and *Coulomb's torsion electrometer*.

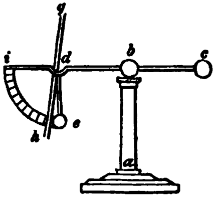
Henley's quadrant electrometer was first made in 1772; it serves to measure the repulsive force of powerful electrical tensions, for which reason it is commonly used with electrical machines. It consists (*fig.* 154.) of a vertical rod, of brass or wood, on one side of which is a graduated quadrant; from the centre of which a fine wire is suspended, carrying at its point a ball of cork or pith. The more powerful the tension which is transmitted along the conductor, the greater the arc through which it will repel the ball.

Fig. 154.



Brande's straw electrometer is a very convenient instrument for many electrometrical experiments. It is represented in *fig.* 155. It consists of a copper wire, *c d*, about 2 lines thick and 8 inches long, which is insulated by its being fastened in a glass pillar, *a b*. To one end of the wire is fixed the ball *c*, to conduct the electricity; the other end, *d*, branches off into a fork, and is furnished with two little sockets, *d*, to receive the axis on which the straw, *g h*, turns; *d e* is a vertical conductor, terminated at *e*, in a short metal cylinder, against which the straw rests when in a vertical position; *e i d* is a graduated glass quadrant, the zero being at *e*. The straw, *g h*, is the electroscopic substance, whose axis at *d* is so contrived

Fig. 155.



that it may slightly preponderate, and in a state of rest take the vertical position *d h*, and move freely about its axis in a vertical plane.

Coulomb's torsion balance is an instrument which has been already described at length in § 92., and a diagram was given of it in *fig.* 36. vol. i. To fit it up for electrical purposes the horizontal needle *b d* should be made of a thin thread of shell-lac, carrying at its extremity, *d*, a small gilded pith ball. At the zero point of the graduated scale, a copper wire enters through the glass cylinder: this wire is also provided with a pith ball, gilded, and of the same size as the other; both balls touch when the torsion needle is in a state of equilibrium at 0. Now, to measure the intensity of an electrical tension, the electricity to be investigated is imparted to the last-named conductor, by which means the ball *d* acquires the like electricity, and is consequently repelled by that of the conductor. The intensities of two electrical tensions may be compared and expressed numerically, if their respective angles be observed, and the calculation performed as shown in § 92. A small gilded ball, or a little roll of gold leaf, fastened to a stick of shell-lac, will be found convenient for transmitting the electricity to be examined to the ball of the conductor.

By means of an electrical torsion balance, Coulomb discovered the law already given in § 475., respecting the decrease in electrical intensity.

This instrument is a very accurate measurer of electrical forces: it has accordingly been much used by Faraday in his researches. The student will find great care and accuracy necessary to obtain correct results in measurements of so delicate a character.

An apparatus in many respects resembling the electrical torsion balance was constructed in 1841 by Oersted; it was subsequently modified by Dellmann. *Fig.* 156 *a.* presents a sectional view of it. *a b c d* is a copper wire which acts as a conductor; it is insulated between *b c*, in a glass tube: a glass or ivory end *f e* stands exactly opposite that portion *c d* of the conductor which rises above the foot of the instrument. From *d* to *e* there runs a thin strip of copper or silver about ¼ a line in width, connected with the conductor *d c* at *d*, but insulated at *e* with gum-lac. The electroscopic substance, whose motion is to show the electricity conveyed by means of the conductor to the strip of

Fig. 156 *a.*

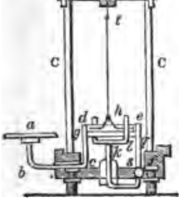
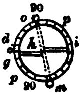


Fig. 156 *b.*



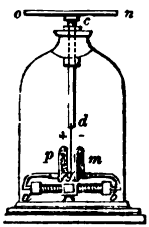
metal, is a fine copper or silver wire, *ghi*, about 2 inches in length, but in such a manner that one half *gh* lies on the right, and the other half *hi* on the left side of the strip of metal. (See the corresponding letters in *fig.* 156. *b.*) This index is attached to a thread *ht*, in the glass cylinder *cc*, which being fixed in the foot of the apparatus serves also to cover it. The cylinder is closed at top with a lid *wx*, in the middle of which is a hole to receive a cork *u*, through which cork the wire *vt* is passed; to this the thread is tied that supports the index. Now, to give the index the position described above, and at the same time to impart the least possible torsion to the thread, the wire *vt* is drawn a little way through the cork, so that the needle can revolve about the metal strip. If the torsion be thus annihilated, the wire *vt* is again depressed till the arms of the index stand exactly in the middle of the strip *de*. To give the desired position to the arms of the index, turn the screw *v* to which the wire is fastened. The whole apparatus is then, by means of three screws at bottom, to be placed in a perfectly horizontal position.

As soon as the electricity is conveyed by the conductor to the metallic strip *de*, the electroscopic needle *ghi* is repelled on both sides. To mark the amount of its declination, and the consequent intensity of the electricity, there is a graduated circle *pq* (*figs.* 156 *a.* and 156 *b.*), one line below the strip *de*. This circle is made of parchment or cardboard, and is attached (and at the same time it is insulated) to the metal by two drops of shell-lac or gum-lac. When the apparatus is not in use, this circle serves also as a place on which to rest the needle.

This instrument is extremely sensitive to low degrees of electricity. Its delicacy may be heightened still further, if we avail ourselves of the inductive influence of electricity, in a way that will be explained in § 486.

To the fourth class of electrometers there belongs only *Bohnenberger's* (improved by Becquérel) *gold leaf electroscope.* The principal parts of this instrument, as improved by Becquérel, are the following:—*ab*, *fig.* 157., is a small dry galvanic pile of from 500 to 800 pairs, about a quarter of an inch in diameter (§ 508.); when the plates are pressed together, such a pile will be from 2 to 2½ inches in length. The wires, which are bent so as to stand above the pile, terminate in two plates *p* and *m*, which are the poles of the pile. These plates, which are 2 inches by ½ an inch, are parallel

Fig. 157.



and opposite to each other. It is convenient for their opposite sides to be slightly convex, for them to be gilded or coated with platinum, and for them to run on the polar wires, by the latter being made to pass through a small hole in them. One of these plates will always be in a state of + and the other of – electricity; between them suspend the very fine gold leaf *dg*, which is attached to the conductor *c d* of copper wire. If the leaf hang exactly between the two plates it is equally attracted by each, and will therefore be in a state of repose. The apparatus should be protected by a bell-glass, fitting exactly, and having an opening at the top through which the copper wire *c d* passes; the wire, however, is insulated by its being contained in a glass tube, which is made to adhere to the bell-glass by means of a small portion of shell-lac or gum-lac. Screw on a metal ball or plate to impart to it the electricity you wish to test, which will be conveyed by the copper wire to the gold leaf, and the latter will immediately move towards the plate which has the opposite polarity. This electroscope is, beyond doubt, one of the most delicate ever constructed, and is well adapted to show small quantities of + and – electricity.

To ensure the susceptibility of electroscopes and electrometers placed under bell-glasses, precautions should be taken to render the air they contain as dry as possible, which may be effected by inclosing in a suitable vessel a little melted chloride of calcium beneath the glass.

§ 481.

In the experiments described in § 479. to illustrate the fundamental properties of electricity generated by friction, the kind of electricity excited was disregarded; but if now we examine more closely, we shall discover that many substances by friction are positively electrified, others negatively, and many both positively and negatively: further, that of two bodies rubbed together, the one will invariably acquire positive, and the other negative electricity. To determine whether a body has + or – electricity, it is necessary that we should have some substance whose electrical state is known; glass rods or sticks of sealing-wax are most commonly used for this purpose. The electricity acquired by the former is called *positive* or *vitreous electricity*, that set free by the other *negative* or *resinous* electricity; it is hardly necessary to observe that the application of the terms positive and negative to these two kinds of electricity is purely arbitrary. Agreeably to the law of electrical polarity (§ 474.), that like electricities attract, and unlike repel, we may easily ascertain of which kind the electricity of any particular body is, by bringing it within the influence of some substance whose electricity is known. This we shall proceed to illustrate in the following experiments:—

First Expt. Electrify two pendulums (*fig.* 150.), or two needles (*fig.* 151.), by means of a glass rod, which you have excited by friction with a piece of silk or cord; they will both acquire the + electricity set free in the glass; it will accordingly repel them, and they will become repulsive to each other.

If we use a stick of sealing-wax instead of the glass rod, precisely similar phenomena will be observable, but in this case the electricity will be —.

Thus we have experimentally proved that similarly electrified bodies repel each other.

Second Expt. Impregnate one of these electroscopic bodies with the + electricity of the glass, and the other with the — electricity of the sealing-wax; the former will be attracted by the negative sealing-wax, and the latter by the positive glass rod, and the bodies themselves will be mutually attractive.

We have now verified the second part of the law of polar forces, that unlike electricities attract.

To test the character of the electricity which is liberated in bodies that are in a state of but slight electrical tension, we are obliged to have recourse to a more delicate electroscope than either of those referred to in the two preceding experiments. The most convenient is Becquérel's pile electrometer, (*fig.* 157.), which shows both the quantity and the kind of the electricity. In other electrometers we are obliged, first, to impart to the electrical bodies the electricity of the body under investigation, and then to test them by means of an excited glass rod or stick of sealing-wax.

Third Expt. Rub a glass tube on a piece of woollen cloth or silk, rolled up tight, and the glass, if tested by an electroscope, will be found to be + electrified, and the woollen cloth or silk to be —. These substances have therefore acquired opposite electricities. It will be found convenient to wrap the silk or flannel in folds over a piece of wood in the shape of a bat.

Fourth Expt. Rub a glass tube up and down the rubber just described, and you will find both the flannel and the silk — electrified; substitute a stick of sealing-wax for the glass, and the electricity will be +.

Rub a smooth glass rod with the hand, and it will become + electrified; but if its surface be rough, similar treatment will render it — electrical.

These experiments prove that the same substance may, by friction, acquire both + and − electricity.

Fifth Expt. Plates, about 3 inches in diameter, either of the substance to be examined, or of some other material on which it can be spread, will be found very convenient for determining the electricities liberated on rubbing two substances together; the plates must be insulated by means of glass handles. After they have been rubbed together, the plates are to be separated, and if offered to a delicate electrometer, it will be found that one of them is + and the other − electrified.

Several eminent men of science have endeavoured to discover a law, by which we might know beforehand what would be the electrical condition of any two bodies when rubbed together. The following rules seem generally to be observed with regard to non-conductors: —

1.) The *hardest* substances appear to be especially susceptible of *positive* electricity.

The diamond, for example, which is the hardest known substance, is invariably + electrified by friction, against any of the other precious stones or against glass; sulphur is not so hard as amber; the former is always − electrified, and the latter + : other instances will readily suggest themselves to the student.

2.) Of two similar substances, that which by friction becomes the *hotter* is *negatively* electrified, and the *cooler* one *positively.*

Sixth Expt. Rub two silk ribbons together, by drawing one cross-ways to the other; that which is drawn lengthwise will have a + electricity, and the other a −.

Rub a piece of ground-glass on a polished glass, the former will be — and the latter + electrified.

It has been further ascertained, that of all known substances, a *cat's back* is the most positively electrical, and *sulphur* probably the most *negatively* so; that is to say, against whatever substance you may rub the former, it always acquires + electricity; and the latter as constantly − electricity. All other bodies may be so arranged between these two extremes, that each on being rubbed with one of the substances, in order below it, will acquire + electricity, and the body with which it is rubbed − electricity; and that the state of tension thus induced is more powerful, the wider the distance in the series between the two bodies. So many circumstances affect the electrical properties of bodies, that as yet no list has been made out that can be regarded as absolutely correct.

Pfaff gives the following list of insulators, beginning with the most positive; if they are taken in pairs, the first will be positive, and the succeeding body negative: —

+ a cat's back, diamond, dog's skin, tourmaline, glass, wool, paper, white silk, black silk, sealing-wax, colophon, amber, sulphur —.

The following is Ritter's list for the electrical tension of both non-conductors and conductors: —

+ diamond, zinc, glass, copper, wool, silver, black silk, grey silk, grey manganeseous earth, sulphur —.

§ 482.

The non-conductors, especially glass and resinous bodies, are used for exciting the highest degree of electrical tension, by rubbing them against some suitable substance, which is generally of a soft elastic texture. Experiment has shown, that an amalgam of tin, zinc, and quicksilver (*a*), mixed with some unctuous matter, and spread on silk or leather, forms the best instrument for exciting glass; resinous bodies are most readily affected by rubbing with the skin of a cat.

a.) Pfister says that this amalgam is best prepared by mixing 2 parts of tin with 3 of zinc, and 4 of quicksilver. The zinc is to be melted first, then add the tin as soon as the mixture becomes fluid, stir it for some time and pour out into a wooden box, on the inside of which you have previously sprinkled some chalk; the mercury should be heated and poured into the box before you add the other two metals; the lid should then be put on, and the box is to be violently shaken till the amalgam becomes cool, when it may be finely pulverized in a mortar.

The conductors, and especially the metals copper and brass, are used for receiving by *conduction* the electricity set free in the non-conductors; to effect this, they must be connected with some non-conducting substance, most commonly with glass. The conductor instantly diffuses (§ 468.) the electricity imparted to it over its whole surface, which is put into a state of electrical tension; the manner, however, of its diffusion is materially modified by the form of the conductor itself. If it be a sphere, then the tension is equal at every point of its surface; if its dimensions be unequal, the tension will be most powerful in the direction of its length, the greatest force being at the extremity of the body. Cylinders will serve as an illustration of what is meant; but if the conductor terminate in a sharp edge or point, the electricity will so accumulate in these parts, that, unless it be extremely full indeed, it will overcome the insulating resistance of the air into which it will make its escape.

The influence which the form of the conductor exerts on the intensity of the electrical tension at its surface, may be thus accounted for. So long as an insulated conductor is in its natural state of electricity; *i. e.* so long as the two fluids are in a condition of equilibrium, it may be assumed that they are equally distributed throughout the body's mass. But when either + or − electricity is accumulated in a body, the single elements of the free electricity repel each other and recede until some resistance is offered to their further expansion. If now the conductor be perfectly homogeneous, no such cause of resistance exists, and the electricity necessarily accumulates at the surface; and if it be surrounded, as it usually is, by the atmosphere, then the latter will oppose the required resistance to the further expansion of the fluid, since the air when *dry* is a very imperfect conductor. Now, if the force be transmitted from the centre, its repulsion will obviously be equal in all directions. In conductors of a spherical form, the electricity will constantly be spread in a film of uniform density, over the surface of the conductor. Hence, also, the more the figure of the conductor differs from a sphere, the more unequally will the fluid be distributed about its surface. The accumulation of electricity will be greatest in those parts which are the most remote from the middle; because in them will be the greatest quantity of repulsive elements; its intensity will increase the more the end of the conductor approaches in form to a point, where the electricity will, of necessity, be the most dense. But the denser the electric fluid at any particular point of the surface of an insulated conductor, the more readily will it overcome the resistance of the air; hence the electricity passes off with such ease from points.

To insulate a conductor completely, so that it may retain the electricity with which it has been impregnated, its figure should be free from all points or edges; even when the best form has been given to a conductor, its tension gradually diminishes; *i. e.* it suffers a loss of its electricity, and after some time it resumes its original condition of quiescence. This loss is owing to the fact, that no absolute non-conductor exists (§ 468.): those bodies to which this name has been given, do but retard in various degrees the escape of the fluid. The atmosphere exerts the most powerful influence on a body's conducting properties, as it is in immediate contact with every part of its surface; the moister the atmosphere, the more rapidly does it convey away the electric fluid. According to Coulomb's investigations, the loss is equal in equal times, the condition of the air remaining the same, and the greater the electrical tension the greater the loss; when the tension is but feeble, bad conductors act nearly as well as non-conductors.

Coulomb made use of his electrical torsion balance to estimate the amount of this loss. According to one of these experiments, the repulsive force of the electricity was proportional to a tension of the wire of 270°. After the lapse of one minute, the tension had to be lessened 6° to obtain an angle of the same deflexion, so that the repulsive force now answered to an angle of 264°. The mean quantity of electricity was consequently proportional to the magnitude $\frac{270+264}{2} = 267°$; and hence the loss of electricity for 1 minute answering to these 6°, would be $\frac{6}{267} = \frac{1}{44 \cdot 5}$. The same electrician found, when the atmosphere was in a dry state, that the loss of electricity was less, being in 1 minute, from $\frac{1}{60}$th to $\frac{1}{70}$th; whereas when it was moist, the loss often amounted to $\frac{1}{20}$th of the mean tension.

The free electricity in conductors is also transmitted by conduction to other similar bodies, and in this transmission the following law has been observed to obtain: — let a and b be two insulated conductors of equal size and of similar shape, and let a only be electrically excited; after contact, they will each possess an equal tension, viz. half that of a before contact. If before contact, their electricities had been equal, but of opposite kinds, they would both be unelectrified after contact, for each conductor would have imparted half its own electricity to the other, so that both containing an equal quantity of + and − electricity, a state of quiescence would be brought about. Next, if a and b were electrified, but unequally, either both similarly or both dissimilarly, after contact, their free electricity would be so distributed, that their tension would be equal; if the conductors were similarly electrified the intensity of their tension would be the mean of their tensions before contact; if dissimilarly, it would be equal to their difference; so that if the intensities of their tensions be expressed by a and b, then in the first case the common tension would be $\frac{a+b}{2}$, and in the other $\frac{a-b}{2}$. Again, if the superficial contents of the conductors be unequal, the quantity of electricity liberated, distributes itself in proportion to the extent of the surface. Lastly, if only one of the bodies a be insulated, and the other b be connected with the ground, the electrical tension of a would cease immediately that it touched b. As a connexion is established with the earth itself, the free electricity is conducted to it so as to be equally diffused over the first conductor and over the earth; but as the latter presents an infinitely large surface over which the electric fluid accumulated on the former, may spread itself, the tension of the conductor is infinitely reduced; *i. e.* it is destroyed.

The law which regulates the conduction of free electricity as given above, may be verified with sufficient accuracy by means of two equal electrometers fitted up on Brande's principle. (See § 480. *fig.* 155.) Strictly speaking, the intensity of the electricity imparted to such an electrometer is not equal to the angle of repulsion shown by the straw on the quadrant, but the difference may be neglected when the angle does not exceed 40°. We may therefore assume that a deflection of 20° or 10° respectively answers to a tension ½ or ¼th as strong as that which causes a deflection of 40°. To prove, however, the exact equality of two such electrometers, give to one of them a charge which will deflect the index, say 40°; bring its ball *c* in contact with that of the other, and observe whether the indices of the two instruments point to an equal degree of deflection; if this is not the case at first, a little correction of the straws will make it right. The following experiments will prove the cases given above.

First Expt. Give to an electrometer *a*, a certain electricity, and touch the ball of the unelectrified one *b*, with that of the other. The straw index of the electrometer *a* will fall about half the number of degrees, whilst that of the second *b* will be equally deflected. Separate the electrometers, touch one of them so as to carry off its electricity, bring them together again, and the same phenomenon will be repeated.

Second Expt. Impregnate both the electrometers unequally with the same electricity, and establish contact between their balls. The straw index of *a*, that which has been the more powerfully electrified, will sink; that of *b*, on the contrary, will rise, so that both acquire equal degrees of tension, which indeed will be the arithmetical mean of the number of degrees shown by the indices before contact. In this instance, also, equilibrium is established.

Third Expt. Impart to the electrometers, *a* and *b*, equal quantities of dissimilar electricities, so that the straws may stand at an equal elevation, then bring their balls into contact, and they will immediately fall to zero, because the equal quantities of opposite electricities neutralise each other.

Fourth Expt. Impregnate the electrometers *a* and *b* with unequal quantities of dissimilar electricities, and bring their balls together. The indices will immediately after contact point to degrees which will give the arithmetical mean of the difference of their previous tensions.

Fifth Expt. Lastly, electrify the electrometer *a* arbitrarily; bring it to *b*, which is connected with the ground; as soon as *a* and *b* touch, the index of the former will fall to zero, its free electricity being diffused over the surface of the earth.

Non-conductors, by virtue of the opposite properties (§ 468.) possessed by them, act very differently in the conduction of electricity. They can indeed be rendered electrical by that means, but only at those points of their surface which are in actual contact with the electrified body. The electricity thus imparted to them is transmitted no further, or if it be, but slowly along their surface; the fluid adheres with a degree of constancy to the points of contact, so that these bodies remain electrified for a length of time even after they have been touched by a conductor. An opportunity will presently (§ 492.) present itself of experimentally verifying this assertion, and we shall at the same time prove that there is a difference in the form of the two species of electricity. The non-conducting property of these bodies is impaired by coating them with any conducting substance: the thicker this coating, the more nearly do they resemble conductors; if the coating be sufficiently thick, they acquire the distinguishing property of conductors (§ 468.), and prove the correctness of the assertion, that free electricity resides only at the surface of a body by transmitting their electricity to the surface of the conducting body with which they are in contact.

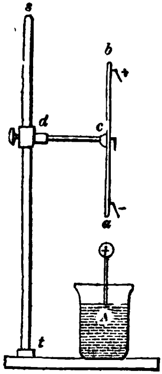
§ 483.

If an insulated conductor be placed *in the vicinity* of an electrified body, the latter will act upon it and produce in it a state of bipolar electrical tension. The body thus rendered electrical by the mere presence of an electrified body without contact with it, is said to be *electrified by induction*. (§ 478.) The phenomena to be observed with regard to conductors thus rendered electrical are the following: —

That part of the conductor nearest to the exciting body has an opposite electricity to it, and the part more remote has a similar electricity. Between these extremes is a point where the conductor is in a state of electrical indifference.

The following simple apparatus may serve to illustrate this law. The conductor consists of a copper wire *a b*, *fig.* 158., about ¼ of an inch thick, and from 8 to 10 inches long: this wire, which serves for the induction of the electricity, is rounded at the ends, and it is insulated by means of the glass rod *c d*, by which it is attached to the upright *s t*. Small pieces of straw are to be fastened at intervals on this rod, especially at the ends and at the middle, these if hung so as to move easily, will serve as so many electroscopes.

Fig. 158.



The electrified substance, by means of which the electricity is to be induced, may be a piece of resin, which if rubbed briskly with a piece of cat's skin, becomes electrified, or a Leyden jar (§ 487.), which has been charged with either + or – electricity. These preparations being made, the following experiments may be performed:—

First Expt. Place the insulated conductor, as the electrical pendulums hang perpendicularly, just over the excited resin, or the ball of the Leyden jar, and you will see:

1. That the pendulums attached to the conductor are repelled from it; consequently the latter is electrified.

2. The deviation of the pendulum is greatest at the ends of the conductor; it diminishes towards the middle, near which there is a point where the electroscopic pendulum does not fly off from the conductor.

3. By means of a glass rod, or a stick of sealing-wax that you have rubbed, examine the electricity of the divergent poles, and you will find, if the inducing body has + electricity, that the end of the conductor next to it has acquired – electricity, and the remote end +. Had the inducing substances been – electrified, these circumstances would have been reversed.

These effects may be thus explained:—The inducing body, which we will suppose to be in a state of + electrical tension, attracts to itself a portion of the – electricity of the insulated conductor that is brought within the range of its influence; the – electricity will therefore become accumulated at that end which is nearest to the + electrified body. The similar + electricity, on the contrary, is repelled, and concentrates itself at the end farthest from the conductor. The whole of the – electricity of the conductor would have collected itself at that spot, did not the + electricity it contains attract the negative particles near to it; the electrical tension is therefore the more intense the nearer the conductor is placed to the exciting body. Towards the middle of the conductor the antagonist forces of the two electricities will cancel each other, and a state of quiescence will be established.

This state of polarity in the conductor is destroyed by removing it beyond the electrical atmosphere of the exciting body, without touching it, so as to carry the fluid off by conduction. The ±

electricities combine, and the conductor recovers its state of neutrality.

> *Second Expt.* Proceed, as we have described above, with both the bodies, viz. with the insulated conductor (*a b*, *fig.* 158.) and the jar A; the return of the former to its state of indifference will be evident by both the pendulums falling down.

If the conductor, whilst in a state of induced electricity, be touched at any point whatever, it will lose the electricity of the same name with that of the inducing body; but the dissimilar electricity at the end nearer to the exciting body will be in a state of greater tension. This phenomenon has caused the first electricity which is carried off to be called *free;* whilst the other, which is retained by the opposite electricity of the inducing body, is said to be *latent.* Remove the conductor in this state beyond the action of the electrified body, and it will again appear electrical, the whole of its surface being electrified with the opposite electricity to that of the inducing body. The electricity held in a latent state in the conductor by the action of the other body, is again set free, and spreads itself over the whole surface of the conductor.

> *Third Expt.* Touch the conductor (*a b*, *fig.* 158.) with your finger, at any part of its surface, and the pendulum *b* will sink, whilst that at *a* diverges still more widely. Place the two bodies apart, and all the little pendulums attached to the body in which the electricity has been induced assume an equal divergence; and if the character of the electricity be tested by means of an excited glass rod, or stick of sealing-wax, it will be found to have an opposite polarity to that of the exciting body; as represented in the figure, the whole of the conductor would be negatively electrified.

From what has been now advanced, it is clear that important differences exist between induced electricity and electricity by conduction. For 1.) Induction occasions no transmission of the free electricity to the other body, and consequently no combination of the $\pm$ electricities, such as obtains when electricity is excited by conduction; but the free polar force in the electrical body exerts a tendency to combine with its opposite electricity in the body on which its inductive influence is exerted. 2.) The distance at which electricity acts in this manner greatly exceeds that at which it acts by conduction; for in the latter case it is necessary that absolute contact should be established, or, if the tension of the free electricities be very great, there may be an interval between the two bodies, if it be so small that the $\pm$ electricities can neutralize each other in the stratum of air which intervenes. 3.) Induction always produces the dissimilar, but conduction produces the similar, electricity to that of the electrifying body; *i. e.* all bodies within the sphere of a positively electrified body's influence are negatively electrified, such as are within the atmosphere of a negatively electrified body are positive.

Thus, although an electrical body, acting by induction on another, sustains no loss as to the quantity of electricity it contains, yet the intensity of its electrical tension is materially modified whilst it is in a state of polar activity. The intensity is lessened by just that amount of the free polar force which is engaged in attracting to itself its antagonist force; and hence the body is enabled to draw still further supplies of electricity from the other body from which it has already derived some by conduction. In other words, during the process of induction a body acquires an additional *capacity* for receiving fresh electricity, the density of which increases in proportion to the quantity added. On the mutual relation which thus obtains in bodies electrified by induction, depends the construction of those important instruments which serve to condense electricity and to increase its power. A full description of these will be found in §§ 486—490.

The inductive influence of electricity obeys the same laws in conductors not insulated as in non-conductors, but in the former its effects are not apparent, as they are neutralized by the connection of the body with the ground, whereas, in non-conductors, the influence is extended to but a small distance from the electrifying body; the resistance to conduction is, of course, the obstacle to its more rapid progress. Beyond these limits an alternate state of tension is found, several *zones* of induced electricity following each other, of which, each succeeding one lies within the electrical atmosphere of the preceding, but as the distance from the original point of excitation increases, the zones become weaker and weaker until they entirely vanish, agreeably to the law which regulates the decrease of electrical influence.

The process of induction may be advantageously applied to the use of the electroscope and electrometer, if the instruments, like Becquérel's and Oersted's, are sufficiently delicate for the purpose. When brought near the electrified body they are excited, and the electroscopic substances diverge agreeably to the law of induction, with the electricity of the exciting body. Whilst the instrument is in this state lay your finger on the conductor, the free electricity will be carried off, and the electroscopic substances will no longer appear to be affected; but if the finger be withdrawn, and the body, whose electricity you are testing, be also removed, the electrometer will again show itself to be in a state of excitement, but with the opposite electricity to that of the body under investigation. This may be proved in the manner which has been already explained several times. The electrometers named above, and also the torsion balance, will be rendered additionally sensitive, by imparting to them a feeble electrical tension, in the first instance by immediate contact, and afterwards bringing the electrical body near them. If the divergence of the indices be increased by this means, the body has the like electricity to that previously imparted; but if their divergence be diminished, the electricities are opposite. In Becquérel's electroscope, the movement of the gold leaf towards the opposite column shows instantly the electrical state of the body under examination. To render Oersted's electrometer (*fig.* 156.), in this respect, as perfect as Becquérel's, Dellmann proposed to add a second conductor of the induced electricity. To effect this, the copper wire *s r k*, insulated by means of a glass tube, is carried through the centre of the foot of the instrument. To electrify the first conductor and the strip of metal *de* by induction, two horizontal arms, *k n* and *k l*, are carried from *k* at a distance of about 1 line below the circular graduated scale, these arms at *n* and *l* are bent upwards towards *o* and *m*. By turning the part *r s* of this conductor beneath the foot of the apparatus, the upright arms *n o* and *l m* can be placed at any distance whatever from the arms *g h* and *h i* of the electroscopic needle. Convey a very minute quantity of either + or – electricity to this induction conductor from the cork ball *s*, and the strip of metal will thereby be instantly electrified with the opposite polarity, the index being repelled by it, takes a position (answering to the + electricities simultaneously acting upon it) between the strip of metal *d e* and the two vertical arms *n o* and *l m* of the second conductor. Screw a condensing plate *a* on the first or prime conductor, induce in it the electricity you wish to examine, and a corresponding movement of the needle will ensue if there be the least trace of electricity.

The law of induction, which we have developed in the preceding paragraphs, is highly important, as it enables us to explain most electrical phenomena (and as we shall see presently, not merely those which are connected with electricity by friction) since induction is the first effect produced by an electrified body on any other that comes within the sphere of its influence. But, for induction, there would be no electrical attraction or repulsion; for as soon as an unelectrified moveable body is attracted by an electrified one, it is not the bodies themselves which excite this action, but the polar forces of the ± electricities which are called into activity by the induction. The same may be said of electricity by conduction, for, before the free electricity of one body is transmitted to another, the former has already effected in the latter the induction of its neutral electricity, and attracted to itself that which is of opposite polarity to its own. When these antagonist influences have been equalized, the transmission or conduction of the surplus free electricity (§ 482.) takes place to the originally unelectrified body; both are, accordingly, similarly electrified, and mutually repel each other.

B. *The Electrical Machine, its Mode of Action and Uses.*

§ 484.

In the fundamental experiments hitherto described, we required but small quantities of electricity and of moderate intensity to illustrate the laws of electrical tension; but if we desire to become more intimately acquainted with these effects when produced by large quantities of free electricity of high tension, we must adopt means, not merely for eliciting a large supply of the fluid, and for retaining it for a length of time, but also for collecting and condensing it when obtained. The most convenient mode of exciteing it is by friction, and the quantity of electricity thus elicited depends on our employing the most suitable substances for the purpose, and, especially, on the extent of the rubbing surfaces. Now, to collect the electricity thus set free, and to impart to it the requisite degree of tension, we must have bodies on whose surface it may be easily diffused and condensed. To accomplish the former of these objects we use non-conductors, to secure the latter we employ conductors.

The apparatus contrived on these principles to develope a large quantity of electricity of high tension is called an *electrical machine*. It consists of three principal parts, viz.

1.) A *non-conductor, by which friction may be excited;* this is generally of glass, presenting a large surface, and having some contrivance attached to it, by which a continued rotatory motion may be imparted to it about a fixed horizontal axis.

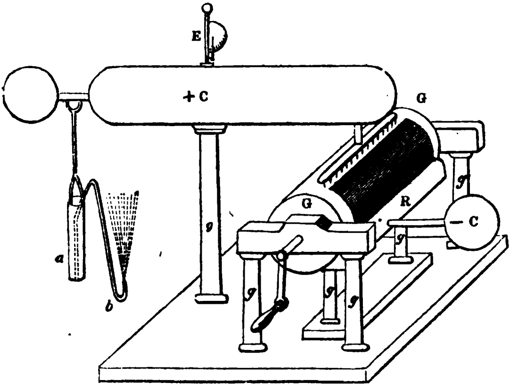
2.) A substance, against which it may be rubbed, called the *rubber*, consisting of a soft, elastic body, of low conducting power, which fits close against some part of the surface of the first-named non-conductor. Whilst the non-conductor is turned round, the friction decomposes the quiescent electricity in the two bodies; the one, therefore, becomes + electrified, and the other —. If the non-conductor be, as it generally is, of glass, it is positively electrified, and the rubber negatively.

3.) The *conductors*, two insulated hollow cylinders, of high conducting power, made commonly of metal, and placed on glass pillars. These conductors are rounded off at the ends, one is intended to receive the positive electricity of the glass, and the other the — electricity of the rubber.

The *cylinder machine* is that which is most generally adopted; it derives its name from a hollow cylinder of glass, placed horizontally, and turned about on its axis by means of a handle: immediately under it is the rubber, which covers from $\frac{1}{8}$ to $\frac{1}{4}$ of the surface of the cylinder, against which it is pressed by a steel spring. That the electricity set free in the cylinder during friction may not be dispersed in the air, a piece of silk is fastened to the upper side of the cushion, extending as far as the conductor, to which it conveys the electricity it carries off from the glass. To collect the electricity set free in the cushion, the latter must be insulated upon glass legs.

The conductor, which is intended for the reception of the electricity from the glass cylinder, is called the *positive conductor.* Its form, as has been stated before, is commonly cylindrical, and its position is generally horizontal, so as to stand at right angles with the axis of the cylinder. That it may receive the electricity from the whole surface of the glass which is subjected to friction, one end of the conductor stands exactly over the middle of the cylinder, having a smaller metal cylinder connected with it, the latter going lengthwise along the cylinder, and being furnished with teeth or points that nearly touch the surface of the glass. The conductor of the cushion, when the machine is fitted up with one, is called the *negative conductor*; it generally consists of a large hollow metal ball, immediately connected by a wire with the cushion or rubber. *Fig.* 159. represents

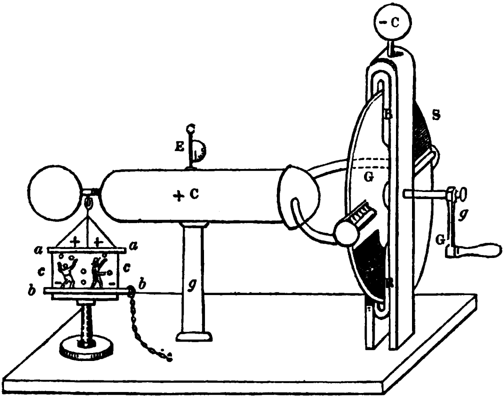
Fig. 159.



an electrical machine, with all the parts we have just described; G G is the glass cylinder, R the rubber or cushion, with the piece of silk S, + C is the positive, and − C the negative conductor, *g g g g* are the glass legs on which it is insulated.

In the *plate-machine*, as its name indicates, a plate of glass is substituted for the cylinder; an axis passes through its centre, the ends of the axis rest in two sockets in two upright pillars, between which the plate is made to revolve by means of a handle, which fastens on to the end of the axis. The cushions, against which both sides of the plate rub, are so fixed between the vertical pillars, that they are pressed opposite to each other against it. These cushions are also provided with silk flaps, which fit close to the surface of the glass. The handle by which the circular plate is turned stands on one side, and on the other is the conductor, consisting of two arms having at their ends small toothed cylinders, which come close to the surface of the glass. If these machines are fitted up with a negative conductor, the simplest plan will be to place it above the two upright pillars which support the machine. This conductor consists of a hollow metal ball, which must be connected with the cushions. *Fig.* 160. represents a plate electrical machine; G G is the plate, R R the rubbers with the silk flaps S S, + C is the positive, and − C the negative conductor.

Fig. 160.



Cylinder machines with equal area of surface, exposed to friction, take up less room than plate machines, but then it is only their outer surface that is available; cylinders are also much cheaper, less readily broken, and the construction of the apparatus is altogether more simple; for which reasons they are in more general use than plate machines.

It may be worth while to remark with respect to the principal parts of an electrical machine, that

The glass cylinder, or plate, is the part on which principally the effectiveness of the machine depends. It has been found by direct experiment, that all kinds of glass are not equally adapted to give out electricity. The best glass is that which is the whitest, most transparent, the hardest and freest from bubbles, and which contains a large proportion of silex. It has also been ascertained that it should not be too thick, in order that the fluid may be quickly excited. In consequence of the properties of the glass, many machines are remarkably effective. In Baumgartner's Zeitschr. f. Phys. u. Mathem. III. 439., mention is made of a plate-machine constructed by Pfister, of Vienna, which possesses extraordinary power: its dimensions are not remarkable; the plate, which is of Venetian glass, is 28 Par. inches (30 English inches) in diameter, and 2 lines in thickness.

The cushion is also an important part of the machine, as on its nature and construction depends the readiness with which electricity is elicited. It consists of a linen cushion of convenient length and breadth fastened to a piece of wood, it is generally stuffed either with horse-hair or with metal filings. The requisite degree and the uniformity of the pressure on the surface of the glass depends on this cushion, to secure which a steel spring is generally placed at the back of it. The neutral electricity of the glass is most rapidly resolved by the aid of the amalgam, the mode of preparing which has been already described at length. (§ 482.) It is generally pulverized very finely, then mixed with a little hog's lard, and spread uniformly on a piece of washed leather, which is fastened on one side of the cushion. I have found the most effectual method is, instead of using a piece of leather at all, to spread the amalgam pretty thickly on the cushion itself, and then to cover it with a piece of silk, so that the amalgam may not be in actual contact with the glass; a sufficient quantity will work through the silk, when the glass presses against it. By this arrangement you avoid the inconvenience of smearing the glass, which inevitably impedes the development of the electricity. One important qualification of the rubber is, that the surface on which the amalgam is placed should carry off as quickly, and completely as possible, the electricity elicited. To effect this a piece of copper or tinfoil of the same size as the cushion, is laid immediately under the surface, coated with amalgam. If the cushion is stuffed with metal filings, this arrangement is not required to carry off the electricity.

The conductors which are intended to receive and accumulate the electricity which the friction liberates, should have a good conducting surface, and their size should be in proportion to the quantity of electricity they will have to receive. The best are made of plates of brass or copper: if of wood or paper they will be cheaper, but less effective, even when covered with tinfoil or silver leaf. The most convenient form, at least for the positive conductor, which is the one in most frequent use, is that of a long cylinder. That the accumulated electricity may not readily escape into the ambient air, a conductor should not have any sharp edges or points. For this reason its ends are hemispherical. (§ 482.) The points on the lesser conductor serve to carry off the electricity more quickly from the glass than it would otherwise pass, it is thence transmitted to the prime conductor which is insulated by being supported on a glass pillar; the insulation is rendered more complete by washing the glass over with a solution of shellac.

The invention of the electrical machine is usually attributed to Otto Von Guericke. The electrical body he used was merely a ball of sulphur, which was excited by friction in the hand. The ball was provided with a handle that it might be turned about with greater rapidity. Glass balls were afterwards substituted for those of sulphur, then cylinders, and lastly plates of glass were used. The important addition of a cushion was made by Winkler to his cylinder machine, which Wilson still further improved by giving it a conductor. Since his time no more parts have been added, although these three have been variously combined and modified. The most famous machine ever constructed, both on account of its size and performance, is that which Cuthbertson made under Van Marum's directions, for the Teylerian Museum at Haarlem. It is a plate machine, having two plates of glass 65 inches in diameter, it has 8 cushions, and its conductors present a surface of 23½ square feet; we shall have occasion to speak of this machine again presently. The machines we have described at length are those which are most extensively used, others have at different times been constructed possessing some peculiarity in form, or in the nature of the bodies, by whose friction the electricity was excited. For further details of these various instruments, we must refer the curious reader to Cuthbertson's, Cavallo's, and Becquerel's works on the subject.

§ 485.

All the effects of electrical tension hitherto described, may be produced much more plainly, and in a higher degree, by means of an electrical machine, than in the fundamental experiments given in § 479.

Insulate both the conductors of a machine, and after the cylinder or plate has been turned round a few times, they will both be in a state of high electrical tension, as a quadrant electrometer E, *figs.* 159. and 160., placed on the positive conductor would immediately show; the conductor in connexion with the glass is positively electrified, that which is connected with the cushion is negatively electrified, as may be easily seen by applying the tests already described. In this state of tension, both the conductors will attract unelectrified bodies held at certain distances from them, and then repel them. So their inductive influence may be observed on electroscopes at a considerable distance.

> A thread 6 feet long was drawn 6 inches out of the perpendicular by Van Marum's great plate machine at a distance of 38 feet from the conductor, and the balls of one of Cavallo's electroscopes diverged ½ an inch asunder when 40 feet from it.

During the revolution of the machine, a luminous appearance is very perceptible, accompanied by a crackling noise; and small sparks are visible in those parts of the cylinder or plate which are not covered with the silk flap.

If the face be placed near the excited bodies, a sensation is distinctly felt, as if spider's webs were being drawn across it; and very shortly after an electrical machine has been in use, the phosphoric odour is strongly perceived.

If both the conductors be insulated whilst an electrical machine is worked, they will acquire only so much electricity as equals the quantity of quiescent electricity which is decomposed by the friction of the glass and the rubber. In proportion as the free electricity transmitted to the conductors is dispersed in the air, the intensity of the electrical tension diminishes. To obtain from the machine a permanent supply of electricity in a high state of tension, it is necessary therefore, that one of the bodies which are rubbed together, should be kept in a state of electrical quiescence, which is accomplished by connecting it with the earth; if we desire to obtain positive electricity, we shall connect the cushion with the ground, if negative, the positive conductor. Generally speaking, for experimental purposes we use positive electricity, which is obtained of greatest intensity by connecting the cushion by means of some good conductor, such as a copper wire or chain, with a large mass of metal, such as a water, gas, or hot-air pipe.

The electricity accumulated in the conductors may be transmitted to other bodies in two different ways, according as the latter are immediately connected with the conductor, or are held at some distance from it. In the first case, the free electricity which is transmitted to the conductor passes on without any perceptible mark to the body connected with it, and the body is then in the condition described in § 482.: that is to say, if a non-conductor, it is electrified only at the points of contact; if a conductor in an insulated position, its whole surface is electrified; if a conductor not insulated, the electricity transmitted to it instantly escapes into the ground; so that neither it nor the conductor manifests the least presence of free electricity. The correctness of the above remarks may be easily tested by the following experiments:

> *First Expt.* Touch an electrified conductor with some point of a non-conducting body which you have previously marked, test the non-conductor by means of an electroscope, and you will find it electrified only at the point which had been in contact with the conductor.
>
> *Second Expt.* If a person stand on an *insulating stool*, *i. e.* on a wooden stool with glass legs, and place one hand on the conductor of an electrical machine which is set in action, a person so placed being an insulated conductor of electricity, will be electrified in precisely the same manner as the prime conductor of the machine.
>
> *Third Expt.* Connect the rubber with the ground, and either suspend a chain or lay your hand on the prime conductor while the machine is being turned round, and the prime conductor will show no mark of free electricity, which will however be developed immediately on removing the hand or the chain.

But if a body be brought gradually towards the conductor while in a state of electrical tension, the conduction of the electricity will take place, even before contact happens, with a *spark* attended with a crackling noise or a report. The *length* of the spark is the greatest distance at which an object can be held from the prime conductor in order to elicit a spark. This species of conduction may be explained by referring it to the inductive influence of the conductor on the body which is moved towards it; those parts of each which are next to the other, as they are brought nearer and nearer together, acquire so violent a degree of electrical tension, that at last the resistance offered by the intervening stratum of air is overcome, and a spark is elicited by the combination of the + and − electricities; the length of the spark varies, being regulated principally by the intensity of the electrical tension and the degree of resistance made by the air: if therefore the air be rarefied, the length of the spark will be increased. It is also in some measure affected by the form of the contiguous surfaces; for if they are flat, they must be made almost to touch before conduction takes place; but if they be convex, as balls, then the longer the diameter the shorter the spark, but the greater its intensity; if, on the other hand, one or both of the conducting bodies terminate in a point, the points will become luminous at a considerable distance asunder, and a continued succession and neutralisation of the dissimilar electricities will be maintained.

All that has just been advanced may be easily verified by fixing balls of various sizes to the extremity of the positive conductor, and presenting to them at different distances, metal balls of various diameters. The effect is rendered more intense by connecting the body you offer to the prime conductor with the cushion. The emission of the electric fluid will be both heard and seen, if the conductor terminate in a point, or if a pointed body be brought near to it.

When V. Marum's great electrical machine had a 4-inch ball affixed to the end of its conductor, and a 12-inch ball was brought towards it, it emitted 300 sparks 24 inches in length in a minute, the sparks being forked like lightning, and having rays from 6 to 8 inches in length proceeding *from their angles*.

This will, perhaps, be the most convenient place for giving a few useful rules to be observed in the performance of experiments, that a well-constructed machine may act with the greatest possible efficiency.

If an electrical machine has been for some time unused, all its parts must be first cleansed from dust: the old amalgam must be scraped off the cushions, and a fresh coating put in its place. Free the cylinder or plate from any amalgam that may be sticking to it, wipe the glass with a clean cloth, having previously washed it, if necessary, with some spirit of wine. If the flap attached to the cushion has become greasy, replace it with a new one. Carefully free the conductors from dust, and see that their surface is perfectly round and even, and that no splinter or point is to be found at any part of their surface by which the electricity might be carried off. Clean, in like manner, all the insulators of the machine, especially the glass pillars, to free them from anything that might act as a conductor. Lastly, establish a connexion with the ground in the manner already shown, taking care that the connexion be uninterrupted. The above are the principal matters to be attended to in preparing the machine itself. Its action will, after all, depend on the state of the atmosphere. The drier the air the more favourable for the performance of electrical experiments; hence, as a general rule, they may be expected to succeed when the wind is in the east or north. The room too, in which you operate, should be dry and free from smoke and vapour; hence the presence of a crowd of spectators, and the burning of many lamps or candles is very prejudicial. For obvious reasons all pointed objects, loose threads, and the like, should be removed away from the machine. As heat contributes materially to sustain the efficiency of the machine, you should place it in winter so near to the fire, that at least the glass and cushions may be affected by the radiant heat; if possible, the room should be dried by means of hot air, both because this is the most effectual method, and because the air thus warmed is remarkably dry.

C. THE DIFFERENT KINDS OF APPARATUS WHICH ACT BY THE INDUCTION OF ELECTRICITY.

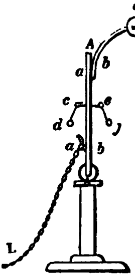
§ 486.

When, as we have already seen, a quantity of electricity of high tension has been accumulated in the prime conductor of the machine, yet it cannot acquire any considerable degree of density because of the tendency which free electricity has to resume a state of quiescence, to which it will sooner or later return, as the insulation is more or less defective. To condense the electricity, therefore, it is necessary to put it in a condition which will allow the opposite electricities to display their tendency to neutralise each other, without, however, actually combining: this is accomplished by the process of induction. The free dissimilar electricities attract and mutually hold each other in a latent state without combination ensuing; and hence, up to a certain point, their density and tension are equally increased.

In the explanation given (§ 483.) of the phenomena of induction, we have shown that this effect takes place under the influence of the atmospheric air; we also noticed the condition of the bodies in which electricity had been induced. In the instance just referred to, the non-conducting substance which impeded the combination of the electricities which were mutually attractive, was the intervening stratum of air; but if we please, we may substitute any other non-conducting body, such as glass, resin, &c. provided only that it be of such a thickness, that the inductive influence of the free electricities may penetrate with sufficient force. For this purpose, two conductors, presenting each a large surface, are employed: on one of them the + electricity, and on the other the — is accumulated; the two surfaces are separated by a non-conductor, which retains them both in a latent and condensed state. A non-conductor equally covered in this way with latent electricity, is said to be charged.

The following fundamental experiment, given by Pouillet, will illustrate the combination of electricity by induction through the medium of non-conducting plates. The requisite apparatus consists of a thin glass plate, A A, *fig.* 161., (a thin plate of sulphur or resin would do as well,) coated on both sides to within 1 or 2 inches of the edge with tinfoil *a a*, *b b*. To each of these coats, a small electrical pendulum, *c d* and *e f*, is attached; *b c* is a wire terminating in a ball, which serves as a conductor of the electricity.

Fig. 161.



Expt. Electrify the metallic surface *b b*, by the conductor C, from the + conductor of the machine, or by any other means whatever, and the two pendulums *e f* and *c d* will be repelled. The pendulum *e f* diverges with + electricity, in consequence of that electricity's extending itself over the outer surface of the metal *b b*. The + electricity spreading over that side of the metal next the glass, acts by induction through the glass on the inner surface of *a a*: thus the neutral electricity (± electricity) is decomposed; the dissimilar kind, in this instance the — electricity, is rendered latent, whilst the + electricity is repelled, and the pendulum *c d* made to diverge with it.

Now touch the coat *a a* with the finger, and the free + electricity becomes saturated with — electricity: and the plate *a a* is again in a state of indifference, whilst the — electricity held in a latent state by the + electricity of the other coat *b b* adheres to the glass beneath *a a*. Now convey a new portion of + electricity to *b b*, induction will again take place on *a a*; touch *a a* and conduct the + electricity to *b b*, so much opposite electricity will become latent on the two glass surfaces, as the resistance of the glass is able to prevent from combining; the plate A A is then said to be *charged*. — The same result is obtained more quickly by maintaining one of the metallic coatings in a state of quiescence, whilst a continued stream of electricity is kept up on the other. This can be effected by connecting *a a* with the ground by a brass chain *a* L, and *b b* with the conductor, while the machine is worked.

When the plate has been thus charged, disconnect it with the conductor and with the ground; the pendulum *c d* will be at rest, while *e f* will diverge with the free + electricity. Now touch the coat *b b*, the + electricity is neutralised and its pendulum falls; the pendulum *c d* of the other coat *a a*, meanwhile rising just as if new electricity had been imparted to it. Its repulsion is, however, owing to a quantity of — electricity being liberated answering to the + electricity carried off from the coat *b b*. Now touch the coat *a a*, and the pendulum *c d* is depressed, while *e f* of the coat *b b* rises; repeat this again with *b b*, and the like phenomenon happens, and thus the glass plate is gradually *discharged; i. e.* the electricities which were held in a latent state are neutralised.

If the experiment last described be not performed after the connexion has been broken, yet you will soon see that the pendulum of the coat *b b*, which diverges with the + electricity, gradually sinks; and that of *a a* begins simultaneously to rise until both have acquired an equal divergence; then they both descend uniformly, until they touch the metal plates, thus showing the plate to be discharged: in this case the discharge has been effected by the gradual loss of the electricity caused by the air. (§ 482.) This process is accomplished the more slowly, the drier the state of the air.

§ 487.

Those important pieces of apparatus by means of which we can accumulate and condense, more or less considerable quantities of electricity, and of great intensity, are constructed on the principle we have just been explaining, viz. that opposite electricities may be held in a latent state. These instruments are *Franklin's electrical plates* and the *Leyden jar;* they differ only in form, the principle on which they both act being the same.

The electrical plates are merely glass plates of a square or oblong shape, coated on both sides to within a little distance of their edges with tinfoil.

The jars are what their name imports, and are covered at the bottom and up the sides to within a short distance of the edge with tinfoil. To convey the fluid to the interior of the jar a brass wire runs through its lid, the upper end terminating in a ball, and the lower end, being divided into several fine points, touches the foil within the jar. These jars are superior to the plates as being more convenient to handle, and less liable to be broken, for which reasons they are generally used.

A jar of this kind is usually charged with electricity from the positive conductor, conveyed to its inner surface by connecting the conductor with the wire by means of a chain, and then setting the machine in motion, or else by holding the knob at the top of its wire near the conductor, while the machine is at work, and a succession of sparks from the conductor to the knob of the jar marks the passage of the charge into the latter. The electricity thus conveyed to the interior of the jar by induction acts through the glass, fixing the opposite electricity on the outer coat, and repelling the similar electricity. If a jar be insulated it can receive only such a charge as equals the quantity of dissimilar electricity which can be rendered latent on the outer surface: but if the jar be connected with the ground, the repelled electricity is continuously neutralised, and its decomposition and dissimulation continues till the intensities of the two electricities (of the + and − electricities) are such as to overcome the resistance of the glass when they will combine.

The quantity of electricity which can be accumulated in an apparatus of this kind is proportional to the area of the metallic surface, the thickness and structure of the glass being equal: the thinner the glass, or the more powerful the induction of the electricity through it, the greater the density of the electricity that can be accumulated in it, or the more intense the charge; sometimes the glass is split, or a hole is made in it, when the condensed electricities overcome the resistance it offers to their reunion. To experiment with large quantities of electricity we employ an *electrical battery*, by which we obtain a large amount of surface. Such a battery is generally made by combining a number of jars of a moderate size, their inner and outer surfaces being connected, so that it acts precisely as one large jar would whose metallic surface was equal to that of the whole battery. The outer coatings are connected by placing all the jars in a box lined with tinfoil; their inner coatings by connecting their knobs by means of bent wires. A battery is charged in precisely the same manner as a single jar; that is to say, a stout wire goes from the end of the prime conductor to one of the knobs, and the bottom of the box is connected by means of a chain with the floor; the machine is then set in motion until the charge has acquired its maximum tension: it will be known when this point has been attained, by a hissing noise proceeding from the wires connected with the interior of the jars, and if the room is dark by their luminous appearance; or it may be ascertained by observing when the index of the quadrant electrometer on the conductor stands at or about 90°.

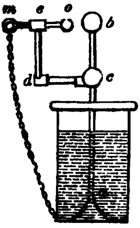
If the outer and inner surfaces of a charged jar or battery be connected by means of a good conductor, the accumulated and latent + and − electricities will combine and neutralise each other instantaneously, emitting at the same moment a spark and a report proportioned to the intensity of the electricity. The length of the spark is measured by observing the distance between the conducting body and the knob of the jar at the time of the discharge.

The Leyden jar, as it is called, was invented by Kleist, (1745,) dean of the chapter at Camin, in Pomerania: instead of tinfoil, the inside was filled with water, and for an outer coating, the wet hands were used. A metallic coating was afterwards substituted. Sometimes instead of lining the inside with tinfoil, the jar is filled with iron filings, or turnings, or the glass is washed with varnish, and iron filings are sprinkled on it. To render the insulation complete, the uncovered part of the glass is washed over with a solution of shell-lac.

Electrical batteries have this advantage over jars of large dimensions, that they can be enlarged or diminished at pleasure, by combining a larger or smaller number of jars, and also that the fracture of a single jar does not put a stop to the use of the whole battery, as would happen if *one* large jar were used. Their size may be very various, it will depend not on the number of the jars, but on the amount of surface they offer covered with tinfoil. The largest batteries ever made were those used with V. Marum's plate-machine (§ 484.); one of these consisted of 225 single jars, each having 1 square foot of tinfoil; it was contained in 15 boxes; another, made afterwards, consisted of 100 jars, contained in 4 boxes, and presented a metallic surface of 550 square feet.

When a number of experiments are performed with jars or batteries in rapid succession, the intensity of the charge may be estimated by the number of turns made by the machine; the usual mode of measuring is, after all, by the length of the spark. To measure this and so at the same time the power of the machine, and also to obtain a number of successive charges of equal intensities, we use *Lane's charging-jar or spark-measurer.* It is a jar of the ordinary size, having a metallic surface of from ½ a foot to a foot (*fig.* 162.), but to the conducting wire *a b* an arm *c d e* is attached, the horizontal part *c d* of which is of glass washed over with shell-lac; the vertical part *d e* is a brass wire having a ring at *e*, in which a graduated bar slides, terminating in a ball at *o*: on this scale the distance of the balls, and consequently the length of the spark, can be measured. To use this instrument connect the end *m* of the bolt by means of a chain with the outer surface of the jar you propose to

Fig. 162.



charge. If the knobs *o* and *b* are placed very near together, a small charge will suffice to combine the + and − electricities of the inner and outer coatings, the intervening stratum of air being penetrated by the spark; but if the distance be increased, then a more powerful charge will be required before the spontaneous discharge will take place. If the same distance is maintained between the balls, the discharge will always happen when the same quantity of electricity has been accumulated. To test the relative powers of two machines, you would place the balls at the same distance, and that would be considered as the more powerful machine which discharged the jar with the least number of turns. Riess used this apparatus as a unit of measure for estimating the intensity of the charge of a battery. For this purpose he insulated the battery, and connected its outer surface with the ball *b* of a Lane's jar, consequently with the interior of the latter. Lane's jar was thus charged with the + electricity repelled from the outer coat of the battery. The number of the charges made by the jar, Riess took as the measure of the quantity of electricity which the battery had received from the conductor of the machine. If the number of discharges made by the jar be divided by the surface charged, the quotient will be the density of the accumulated electricity.

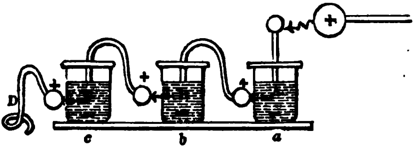
The following simple experiment will render visible the repulsion which takes place in charging a jar:—

First Expt. Powder a glass plate or a cake of resin with semen lycopodii, and insulate the outer coat of a Leyden jar by placing it on this plate. You will observe as each spark goes from the conductor of the machine to the ball of the jar, that the dust lying on the plate of glass is repelled in rays from the periphery of the outer coat of the jar.

In like manner, several jars may be charged by a single one in connection with the conductor of the machine, the electricity driven off from the outer coat of each jar effecting the charge of the next, each of the jars being properly insulated. The following experiment will illustrate this:

Second Expt. Place the jar A (*fig.* 163.) on a plate of glass or Indian-rubber, so that its knob shall be about 1 inch or 1¼ inch from the conductor. Insulate the jars B and C in like manner by standing them on plates of glass, *b* and *c*, and bring their knobs as shown in the diagram within about 1 inch of the outer coat of the preceding jar; against the outer coat of the last jar C place a conductor D not insulated. When a spark is emitted from the conductor of the machine to the knob of the jar A, there is emitted a spark between the outer coats and the knobs of the other jars,

Fig. 163.



caused by the + electricity which is repelled, and the conducting body D receives simultaneously the electricity repelled by C, and conveys it away into the ground.

Jars are commonly charged with + electricity; but if it is wished to charge them with negative electricity and the machine has such a conductor, it is merely necessary to present them to the negative conductor instead of to the positive; but in that case the cushion must not be connected with the earth, but in its place the positive conductor must be so connected. A jar may even be charged with negative electricity at the positive conductor by holding it by the wire which has a knob at its extremity, and receiving the spark on the outer coat of the jar, or the jar may be insulated, and its outer coat be presented to the conductor, and its inner one be connected with the earth: in either case it will be seen without further explanation that − electricity becomes accumulated in its interior.

As has been already stated, the discharge of a jar or battery by means of a good conductor is attended with the emission of a strong spark: the discharge may, however, also be accomplished gradually by means of a bad conductor. Alternately touch with any conducting body the inside and the outside of an insulated jar or battery that has been previously charged, and each time you will perceive a feeble spark of free electricity from each coating. These sparks become less and less distinct until the electricities accumulated both inside and outside the jar are neutralised, and the discharge is completed. A jar may also be quickly discharged by presenting to its inner coating, or, what is the same thing, to the knob of the wire that is connected with it, any metallic point or a piece of touchwood. The atmosphere also effects a discharge whose rapidity depends on the moisture of the air. Hence are deduced those precautionary rules which must be observed in the performance of electrical experiments, so as to avoid a needless expenditure of the accumulated electricity.

If several conducting bodies be presented at once to a jar or battery, it will discharge itself by all of them, in proportion to their respective conducting powers; hence, a loaded jar may be discharged with both hands without any very sensible effect, by holding a chain in the middle in the two hands, and discharging the jar by the ends of the chain passed between the fingers.

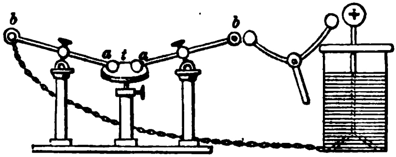
Sometimes it happens, that during the process of charging a jar or battery, it will spontaneously discharge itself; this it will do through the glass at some point where it is unable to resist the tension of the antagonist electricities, which, in their passage through the glass, are occasionally found to make a hole through its substance. A jar that has been thus damaged is useless for electrical purposes afterwards. A spontaneous discharge does not necessarily cause a jar to be pierced, if the stratum of air separating the inner and outer coatings be penetrated by the spark, which will happen whenever the distance between them is less than the length of the spark answering to the charge at that moment contained in the jar.

The following pieces of apparatus are used to effect the easy and safe discharge of jars and batteries: —

1.) *The common discharger*, which is merely a glass handle, at the extremity of which are two bent wires terminating in knobs. They are provided with a sort of hinge, to admit of their being opened to any convenient width. When a jar is discharged, one knob is brought to the outer coat, and the other is made to approach the knob of the jar. To discharge a battery, fasten the chain connected with the lining of the box to one knob of the discharging rod, and bring its other arm towards some conductor that is connected with the inner coatings of the battery.

2.) *Henley's universal discharger* (*fig.* 164.) consists of two copper wires *a b*, which are insulated by being placed on two glass pillars; these wires can be moved freely in their sockets, and set at any particular distance apart, so as to convey the charge through any object laid on the little table *t*. The ends *b* are generally in the form of rings, for the sake of hanging chains to them; the knobs at *a* can be

Fig. 164.



removed at pleasure, so that the wires may terminate in points. To discharge a jar or battery by means of this apparatus, attach a chain, which is connected with the outer coating to one of the rings *b*; connect the other ring in a similar manner with one arm of a common discharging rod, and place its other arm in contact with the knob of the jar.

Even after a discharge has been thus made, you will invariably find a greater or less residuum of electricity in the jar or battery. This can be got rid of by repeating the discharge several times, until the electricity which adhered to the surface of the glass has been removed. Riess found that the quantity of electricity lost by the first discharge amounted to $\frac{11}{15}$ of the entire charge.

Faraday and Riess have both, among modern electricians, distinguished themselves by their delicate experiments and their investigations into the nature and properties of electrical charges: the last-named philosopher has, indeed, endeavoured to discover the law which regulates them.

§ 488.

The discharge of a jar or battery is the instant when the electrical forces, in their primary state of activity, pass from a state of tension into their secondary condition, known as the *electrical current.* (§ 473.) The equilibrium which subsisted between the ± electricities accumulated in the inner and outer coatings of the jar is destroyed, the two fluids are set in motion, and at that instant their *neutralization* takes place. This electrical action is carried on along the conductor joining the *two* coatings, and as Wheatstone has lately shown, by means of a simple experiment, the movement of the fluids undoubtedly takes place in opposite directions from the two coatings. Hence, in fact, there are two currents moving in contrary directions; that which issues from the positive coating is called the *positive* current, that which proceeds from the *negative*, the *negative* current. As it might cause confusion to speak of both currents, when our attention will be confined to one only, we shall say, once for all, that when no particular distinction is made, the positive current is to be understood.

This current, or the propagation of the state of quiescence, is of so short a duration, that it may be regarded as *momentary.* Wheatstone's experiment has recently furnished us with an approximate measurement of its duration, from which it appears, that in a copper wire it travelled at the rate of 288,000 miles in a second.

The different phenomena which characterize the electrical current, and which we have briefly noticed already (§ 476.), are caused by the neutralization of the ± electricities in all bodies that form parts of the circuit thus instantaneously traversed.

If the circuit passed over by the current of electricity be interrupted at one or more points, there will be a spark at each of these intervals, indicating the direction taken by the fluid. The light is generally white and intensely bright; under certain circumstances it is coloured; its duration can be estimated only approximately by calculation, and is less than the millionth part of a second. We may infer, that sensible caloric is combined with the light, as the spark in its passage consumes substances which can be burnt only by the application of a considerable heat.

If other non-conducting bodies, besides the atmosphere, form a part of the electric circuit, and if the resistance they offer to the combination of the ± electricities be less than the force with which these tend to unite, then the bodies so interposed will be penetrated by the electric spark which, in its passage, will suddenly expand them, or even cause a disruption of their parts. In such cases, the electric spark exhibits, on a small scale, the same phenomenon as the lightning displays on a grand scale in the electrical processes of the atmosphere.

If the ± electricities resume a state of quiescence in conductors which offer an inconsiderable resistance to their combining, they disappear as 0 electricity, without any luminous or thermal phenomenon being developed. If, on the contrary, the conductor has a high retarding power, in proportion to the quantity of ± electricity which is to be neutralized, then the temperature of such a body will be raised, and the greater the resistance it opposes, the greater the heat it will acquire; so that even the hardest substances become incandescent, or are fused, or are even driven off in vapour.

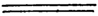
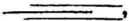
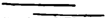
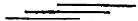
Another purely physical property possessed by the electric current is its power of affecting magnets within a certain distance. This influence is displayed, partly by its disturbing the state of magnetic equilibrium, and partly by attracting and repelling magnetic substances. As the effect produced is only momentary in its duration, these phenomena are not so characteristic of the electric current as when caused by the permanent current which contact electricity generates. For this reason we merely notice the well-established fact, that the momentary electric current has this magnetic property, reserving the closer consideration of the subject to that section of this work which treats especially of electro-magnetic phenomena.

The momentary electric current is further characterized by peculiar physiological effects, exciting convulsive movements in any living animal that forms a part of the circuit. At the instant the current is transmitted through the frame the nerves are excited, and the muscles contract with more or less violence, and even after the death of the animal these movements continue to be perceptible.

If the current be transmitted through any imperfect conductor, especially through a moist substance as water, its properties are materially affected. The spark accompanying the discharge of a jar into such a body is short, dim, generally of a violet colour, and unattended by any report. If the human body form a part of the circuit, the current excites no muscular contraction, but a peculiar pricking sensation. It is remarkable that gunpowder can be ignited only by such a current as this; when a spark is transmitted from a good conductor, it has no effect on the powder.

Lastly, the current possesses chemical properties decomposing into their constituent elements, such chemical solutions as admit of being easily resolved. The effects thus produced are not very powerful, as a continued current is required to effect most chemical decompositions, and we can obtain only an approximation to it by transmitting a rapid succession of sparks through the solution we wish to resolve into its elements.

The principal experiments for illustrating the above-named properties of the electric current will be described in § 491—500.

Wheatstone found in his important experiment, that when a Leyden jar was discharged by means of a long copper wire, the continuity of which was interrupted in the middle and also near to the coatings of the jar, that the sparks appeared simultaneously at the ends of the wire, but that in the middle it appeared later. Hence he inferred, that an electrical stream issued at the same instant from both the surfaces of the jar, and that they met a little after in the middle of the wire. The ingenious contrivance Wheatstone then adopted, enabled him to measure the velocity with which the light travelled, and also the time it continued visible. The breaks in the conducting wire of his apparatus were placed in a straight line, so that the break in the middle of the wire was between the other two; exactly opposite he placed a small metallic speculum, in which he could view the images of the three sparks; the mirror was made to revolve with great rapidity about an axis parallel to this line. Now, as the image of an object seen in a mirror appears to be prolonged, if the mirror be turned on an axis, it is obvious that the rotation of Wheatstone's mirror gave to the three sparks the appearance of three parallel lines, which would of necessity begin and end at uneven points, if there were any perceptible interval of time between the images of the sparks being received on the mirror. The important result was now obtained, that when the velocity of the mirror's rotation was small, the position of the lines was even, thus,  ; but when the rate at which it turned was sufficiently accelerated, they assumed this appearance , when the mirror revolved towards the right hand, and  if towards the left; but under no circumstances did the lines stand thus , as they must have done had the current been transmitted from one extremity of the wire to the other; and had its passage occupied any perceptible space of time. From a consideration of these facts, this philosopher inferred that they did not admit of being accounted for on the supposition that a single fluid traversed the wires, but that we must assume that two fluids enter the opposite ends of the conductor at no perceptible interval of time, but that they traverse half the length of the wire in a space of time that admits of being measured.

Again, as according to catoptrical laws (§ 291. 3.), the image of an object in a revolving mirror has twice the angular velocity of the latter: it follows, that if the mirror in one second makes a revolutions, the image of the spark, supposing it also to last 1 second, would make $2a. 360°$. If the image of the spark make an arc of b degrees, it would have continued luminous $\frac{b}{720a}$ of a second. When the mirror was made to revolve 800 times in a second, the image of the spark at a distance of 10 feet, appeared to an eye placed close to the mirror, to make an arc of not quite $\frac{1}{2}$ a degree in length. In this case the arc of the spark b, must be less than $\frac{1}{2}$ a degree; and as $a = 800$, the duration of such spark must be less than $\frac{\frac{1}{2}}{720 \,.\, 800}$, *i. e.* rather less than 0·00000087 of a second. — Of this instantaneous but intensely powerful effect of the electric spark, any person may satisfy himself by looking at a disc by this light; the disc should be made to revolve so rapidly, that the images depicted on it cannot be distinguished with an ordinary degree of light because their impressions become confused in the eye. (§ 347.) Viewed by the illumination of an electric spark, such a disc seems stationary, and the objects painted on it are seen in their true form and position. If one of Newton's coloured wheels (§ 324.) be viewed in the same manner, the individual sectors will be seen of their fundamental colours, notwithstanding its rotation; vibrating cords seem to be in a state of repose in their undulations; and a succession of drops which generally appears to the eye as a connected stream, is seen to be but a series of drops, because the impression of each image lasts for so short a time, that the position of the moving bodies is not altered. The following experiment will confirm what has been just advanced: —

Expt. Place the two balls of a universal discharger (*fig.* 164. *aa*) about an inch asunder; connect one of the wires by a chain with the conductor of the machine, and the other in like manner with the ground. As the machine is turned round intensely bright sparks will pass at intervals from one of these balls to the other. A small Lane's jar may be used instead, and thus a still more intense spark will be obtained. — If a rapid rotation be imparted to a parti-coloured disc, or to a spiral wire held near the place where the discharge takes place, the phenomenon described above will be plainly observed as the sparks are emitted.

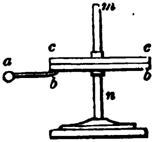
The length of the wire, along which Wheatstone conveyed the electric current, was ½ an English mile; to go over half this distance, or ¼ of a mile, it required about 0·00000087 of a second; whence it follows, that its velocity in 1 second was $\frac{\frac{1}{4}}{0{\cdot}00000087}$ of a mile, or 288,000 miles.

Wheatstone announced his important discovery in 1835, in a lecture which he read before the Royal Institution.

§ 489.

Another kind of apparatus, called a *condenser*, depends, like the Leyden jar, on the induction of electricity, and on its being held in a latent state. This instrument is used to detect the presence of electricity, and to determine its kind in bodies where it exists with so low a degree of intensity, as not immediately to affect the most sensitive electroscopes, requiring to be collected and condensed before it gains a sufficient degree of tension to cause the electroscopic bodies to diverge.

Fig. 165.



It consists (*fig.* 165.) of two circular discs of copper or brass, *c c*, *b b*, whose touching surfaces are highly polished, and between which some feeble non-conductor is interposed: this may be either a thin film of air retained between the two plates by three drops of sealing-wax being so placed near the edges of the plates as to keep them asunder; or else their surfaces may be done over with a thin and uniform coat of varnish. Pfaff recommends that amber varnish be used for this purpose, as being a good insulator, and less liable to be abraded than other varnishes. The upper plate *c* is called the *collector*, the lower one *b* the *base*. Both are furnished with glass stems *m n*, so that the collector, by means of the handle *m*, may be detached in an insulated state from the base. To connect the base with the ground, attach a chain to the wire *b a*, having a knob *a* at its extremity. — Some bad conductor, such as white marble or dry polished wood, will do for the base instead of metal; the collector then will not require to be varnished, and the connexion of the base with the ground may be dispensed with. Instruments made in this manner act more imperfectly than the others.

The apparatus is thus used: — Place on the collector *c*, or connect with it, the body whose electricity you wish to investigate; touch the ball *a* with your finger: the electricity thus transmitted to the collector acts by induction through the thin non-conductor on the base, and confines its opposite electricity in a latent state, repelling at the same time its similar electricity. As now the base is connected with the ground, a constant supply of neutral electricity is conveyed to it, which in its turn undergoes a similar decomposition. This process lasts until the condenser has received the full charge answering to its surface. Raise the collector, which you lay hold of by its glass stem *m*, suddenly, keeping it parallel with the base, and the latent electricities will be again set free. The electricity of the body under examination will have accumulated itself in the collector, and the dissimilar electricity will be found in the base. Present the collector to any delicate electrometer or electroscope, and the accumulated electricity will be measured.

The most convenient arrangement is, when the base is screwed on the conductor of a delicate electrometer (*ex. gr.*, Bennett's, Oersted's, or Becquerel's, § 480.), in which case the mode of experimenting is slightly different. The body to be examined is put into immediate contact with the under plate *b* (*fig.* 153.), to which, for this purpose the metal pin with the ball is attached, and by means of the finger you connect the condenser with the ground. After the electrical body has remained a sufficient time in contact with the ball *a*, it is to be removed, and the conductor *c* lifted up by its glass stem, by which means the electrometer immediately shows the electricity set free in the lower plate *b*. In this case, the apparatus is exactly reversed from what it was in the other experiment, the lower plate being the conductor and the upper the base; however, the latter may be put in contact with the body under examination, and the lower can be connected with the ground, in which case it is readily seen that the electrometer must indicate the opposite electricity.

Though in most cases a *simple condenser* of the kind described will be sufficient to condense the sensible electricity, or to impart to it the requisite degree of tension, yet this does not always happen. A second condenser with smaller plates must then be used, to which the electricity already accumulated in the greater one may be transmitted and condensed a second time. This *double condenser*, originally invented by Cuthbertson, and since simplified by Peclet, consists of three discs of plate-glass, the whole surface of which is covered over with leaf-gold. The lowest, which we will call *a*, is attached to the conductor of an electrometer, and its upper face is varnished over: the second plate *b* lies on this, and is varnished on both sides. A small copper gilt stem is fastened on one point of its circumference, and in the middle it has a glass handle like a common collector. The third plate *c*, which is to come on this second one, is varnished only on the under-side; it has a hole drilled through the middle, and is furnished with a glass tube which incloses the glass stem of *b*, but is rather shorter than it. This double construction effects the repeated condensation in the following manner: — Lay the body to be examined on the upper plate *c*; touch the middle one *b* so as to establish a connexion between it and the ground; lift off *c*, and touch *a* in a like manner. Replace *c*, touch it again with the body and repeat the former process, until at last, by means of the glass pin, the plates *b* and *c* are lifted up together, when the whole of the electricity accumulated in the undermost plate becomes sensible, as may be seen by the divergence of the electroscopic bodies. Since brass and copper plates can, by the galvanic process, be so readily gilded or covered with platinum, it will for many reasons be advantageous to use such discs instead of glass plates.

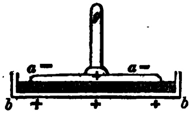
Volta, in 1783, invented this apparatus, which is of great value, as by means of it the existence of sensible electricity has been discovered in many bodies on their being brought into contact with each other, as also in many chemical and atmospheric processes, in which the presence of electricity could not have been detected by any other mode.

§ 490.

The *electrophorus* is also an apparatus invented by Volta, 1775, which possesses the property of maintaining for a length of time, by its inductive process, the electrical tension which friction had excited in a non-conductor.

It consists of two principal parts, viz. of a common circular

Fig. 165 *a.*



level disc of resin (*b*, *fig.* 165 *a.*) and a brass plate *a*; the cake of resin which lies in a metal mould, or plate, is the base of the electrophorus; and the brass-plate, which should be perfectly round and smooth, is insulated by means of a glass handle *g*. This instrument is thus used:— The resin is rendered negatively electrical by friction with a cat's skin. The sensible electricity now acts by induction through the mass of resin, which should not be more than ½ an inch in thickness, reducing to a latent state a quantity of + electricity on the opposite side corresponding to its own attractive force; by this means both the − and + electricities may be retained in a latent state for months or even years. If the brass plate be laid on the cake of resin, it also is rendered electro-polar by induction. In this state the following phenomena may be observed in the electrophorus:—

Expt. 1.) Lay the brass plate on the resinous surface, touch it with your finger, and a small spark will be emitted from the brass. This is owing to the − electricity being repelled by the induction of the cake; the + electricity of the brass, on the contrary, is held in a latent state by the − electricity of the resin.

2.) A similar effect follows if the base be insulated, the resin rubbed, and the finger laid on the mould or frame that contains it. In this case it is the + electricity of the mould which is rendered sensible by the induction of the under-surface of the resin.

3.) Touch the brass plate so as to carry off its — electricity, lift it up by the glass handle, by which means it will be insulated, and it will emit another spark. Now the + electricity is rendered sensible, which was before held in a latent state by the resin.

4.) Raise the plate again in an insulated condition by its handle, without previously touching it, and if the apparatus is in good order it will not be at all electrically excited. This is owing to the + and − electricities, which had been kept asunder by the inductive influence of the resin, combining, and thus neutralising each other after the brass had been separated from the resin.

5.) Replace the brass plate, touch the mould with your thumb, and lay one finger on the brass plate, and you will experience a slight shock in your hand. By this contact the — electricity, of the plate being repelled is counteracted by the + electricity of the mould, the antagonist fluids meeting in your hand. Now raise the plate by its glass handle, thus insulating it, and the + electricity it contained in a latent state will be emitted with a spark.

That the dissimilar electricities are rendered sensible in the manner just described, may readily be shown by a Becquerel's electroscope.

From all that has been advanced, it is evident that the electrophorus acts precisely in the same way as a Franklin's plate (§ 487.); it may therefore be charged like it, by conducting *ex. gr.* — electricity to its brass plate; the fluid will then adhere to the surface of the resin just as if it had been excited by friction.

An electrophorus may also be used instead of a small electrical machine, as we can draw sparks from the plate when lifted up, after it has been put in contact with the cake, in precisely the same manner as from the positive conductor of a machine. This may be repeated indefinitely, by replacing the plate so as to establish contact between it and the resin, and then removing it: to ensure that these surfaces do actually touch, lay a piece of tinfoil on the cake, which will cause the sensible + electricity of the mould to combine with the — electricity of the plate each time the latter is replaced. That the electricity of the resin is not carried off and weakened, may be thus accounted for, that it acts, not by conduction, but solely by *induction* on the neutral electricity of the brass plate.

The power of an electrophorus depends on the size, hardness, thickness, and polish of the cake of resin, and on the accuracy with which the under-surface of the plate fits it; the most important point to be attended to is the quality of the resin. Robert says that the best composition is 10 parts of gum-lac, 3 of colophon, 2 of white wax, 2 of Venetian turpentine, and ½ a part of pitch; an electrophorus thus prepared will both give out a large quantity of electricity, and will also retain it for a length of time. Pfaff recommends a mixture of 8 parts of colophon, 1 of gum-lac, and one of Venetian turpentine. As a good electrophorus retains for a long time the electricity rendered sensible in it, it is frequently used for igniting a jet of hydrogen gas in Volta's inflammable air lamp.

D. THE PRINCIPAL PIECES OF APPARATUS USED WITH AN ELECTRICAL MACHINE FOR THE PERFORMANCE OF EXPERIMENTS.

§ 491.

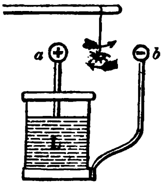
Having become acquainted with the laws of electricity and with its fundamental properties and modes of action, as also with the construction and use of the most important kinds of electrical apparatus, we will now proceed to describe some of the chief experiments in electricity, which may serve to illustrate and confirm the explanation already given. Some of these experiments can be performed by means of the electricity of the conductor of an electrical machine in full work, while others will require a greater quantity of more intense electricity, for attaining which we shall be obliged to use jars and batteries.

I. *Electrical motions* generated by the attraction and repulsion of electricity in a state of tension: —

Expt. 1.) *The dancing figures and pith balls.* The apparatus employed in this experiment consists of a round metal plate (*aa*, *fig.* 160.), suspended from the conductor of the machine; *bb* is a similar plate placed beneath the other and parallel with it; *b b* is connected with the ground; *c c* is a glass cylinder between the two. By turning the machine, *a a* becomes + electrified, and *b b* by induction negatively so. Some light bodies, pith balls or pith figures, are laid on the lower plate, and as they become excited they are alternately attracted and repelled. The figures may also be made to dance, by holding a common bell glass over the end of the prime conductor for some time, whilst the machine is in action, and then placing it on a plate containing the figures, the metal plate being in connection with the ground.

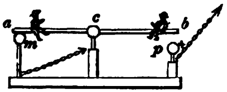
2.) *The electrical spider.* In *fig.* 166., L represents the Leyden jar, to the outer coating of which a wire is attached, having a knob *b* at its extremity. If the jar be charged with positive electricity, *a* is + electrified, and *b* —. Any light substance, such as a spider or other toy, cut out of pith, suspended between these two balls, provided also that it be insulated, will be alternately attracted and repelled by *a* and *b* until the jar is discharged.

Fig. 166.



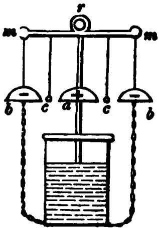
3.) *The electrical see-saw* (*a b*, *fig.* 167.) is a small strip of wood covered over with silver leaf or tinfoil, insulated on *c* like a balance. A slight preponderance is given to it at *a*, so that it rests on a wire having a knob *m* on its top; *p* is a similar metal ball *insulated*. Connect *p* with the interior, and *m* with the exterior coating of the jar; charge it, and the see-saw motion of *a b* will commence from causes similar to those which excited the movements of the pith figures.

Fig. 167.



4.) *The electrical bells* (*fig.* 168.) *m m* is a bar of metal, from which three bells, *b a b*, hang, and between them the clappers, *c c*. The bell *a* is attached to a wire, but the other two *b b*, and the clappers *c c*, are suspended by silk threads; the bells *b b* are further connected with the ground by means of chains. This apparatus is either fastened by the bell *a* to the conductor of a Leyden jar, or else it is hung by the ring *r* to a chain attached to the prime conductor of the machine. When the jar is charged, or the machine set in motion, the bell *a* is + electrified, and the other two *b b* are − electrified; hence the clappers *c c* between them are alternately attracted and repelled.

Fig. 168.

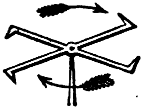


5.) *The electrical cotton.* A bank of cotton, or a downy feather, suspended by a thread from the prime conductor, expands in all directions when the machine is set in action, the fibres seeking for some object connected with the earth. Present a needle or any pointed thing to them, all the ends of the cotton or feather will be drawn together towards it, away from the conductor of the machine; a bundle of silk or glass threads would act in a similar manner. If a person stand on the insulating stool, and lay his hand on the conductor whilst the machine is at work, the hair of his head will stand out in the same way. In this instance the similarly electrified parts of a body are mutually repulsive.

6.) *The electrical shower.* A jet of water from a small Hero's ball or a syphon, insulated and connected with the prime conductor, falls down in a fine shower. A very simple modification of this apparatus is represented in *fig.* 159. *a* is a metal cylinder hung by a chain from the prime conductor; water is poured into it, which is conveyed away by the glass syphon *b*, and the stream is dispersed into the finest rain as it descends, when the machine is set to work.

7.) *The electrical wind.* The flame of a candle held near to a point or small ball attached to the prime conductor, will be extinguished by the current of electricity, caused by the repulsion of the electrified air.

Fig. 169.



8.) *The electrical fly-wheel.* A metal S or cross (*fig.* 169.) turning on a point which is fixed on the prime conductor, or on the knob of a Leyden jar, revolves on the same principle as Segner's water-wheel (§ 165.), or as the steam ball or aeolipila (§ 419.), in an opposite direction to that in which the electricity issues.

§ 492.

II. *Difference observable in the + and — electricities,* shown partly by their luminous appearance, and partly by their mechanical effects.

Expt. 1.) The electricity emitted from a small ball, or from a rounded point attached to the prime conductor, radiates in a stellated form, with a reddish blue light. That discharged from a similar knob or point of the negative conductor is seen as a luminous point or star.

Bring a pointed body near to the positive conductor, and you will have a luminous speck, offer it to the negative conductor, and the light will be seen to radiate in all directions. Hence it appears that wherever one of the electricities is sensible, the other is always attracted to it, and, consequently, that none of the electricity is absorbed in the points which are brought together, but that ± electricities are merely brought into a state of quiescence.

2.) Discharge a positive spark on a polished resinous surface, from the knob of a loaded jar, and on another part of the same surface discharge a negative spark; the + and — electricities will be retained, in a latent condition, on the spots against which they were respectively directed. Now, sprinkle the resin with semen lycopodii, flowers of sulphur, or any similar substance, and particles of the dust will be attracted and retained by the electricities. Blow away the rest of the powder from the surface of the resinous body, and at the spot which was positively electrified, you will see a radiant star-like figure; at the negatively electrified spot there will be merely a round clouded speck. These figures have been called from their discoverer, *Lichtenberg's figures.* — Use of metal rings or bells in electrifying the resinous cake. — Letters or other figures depicted by means of a Leyden jar. — Utility of warming or even melting the surface of the cake before the experiment is performed.

3.) Electrify in a similar manner a cake of resin, positively in some places and negatively in others, and with a soft piece of linen spread over it a mixture of flowers of sulphur and red oxide of lead. The positively electrified spots will be yellow with sulphur, and the negatively electrified will be red with the lead. In consequence of the friction caused by the linen rag, the sulphur attracts the — and the lead the + electricity; the dissimilar electricities are accordingly repelled from those particular spots.

4.) Place two Leyden jars of equal size, the outer coat of one being positively, and that of the other negatively electrified, from 3 to 4 inches asunder on a glass plate, the upper side of which is sprinkled with semen lycopodii, and the under-surface coated with tinfoil. Connect the two inner surfaces of the jars by a common discharging rod, and a spark will be emitted from their outer surfaces. After the discharge, the figures of their respective electricities will be visible in the dust around the jars, and all the dust will be driven away from the path traversed by the spark. This path is generally traced over with positive figures from the positive coating, and with negative figures from the negative coating. These marks disappear near the spot where the two fluids meet, and at the point where the ± electricities combined to form 0 electricity, there is frequently to be seen a large round speck, bounded by no figures whatever.

§ 493.

III. *Electrical luminous phenomena* invariably occur, as we already know, where the ± electricities combine in their passage through the air. They appear as a dim light or glimmer proceeding from the electrified body, when the neutralisation of the two fluids is effected immediately by the air itself, as is the case when a current of electricity is emitted from points or small knobs; but when the current is transmitted through a good conductor, a spark is emitted at every point where the continuity of the conductor is broken. The intensity of the electric light depends partly on the density of the accumulated electricity, and partly on that of the gas through which the spark passes; the denser the medium, and the more intense the electricity, the brighter and shorter will the spark be. In rarefied air the light is longer, broader, and less powerful; it also assumes a rose or violet tinge; its hue is further affected by the nature of the conductor through which the current is transmitted. When sent through gold it is green; through silver, red; through tin or zinc, white; through water, yellow, inclining to orange. On these different peculiarities depends the construction of a variety of electrical instruments, by means of which the most surprising and beautiful luminous effects are produced. Want of space prevents our briefly describing more than a few of the principal.

Expt. 1.) *The spangled rod* is a glass tube some feet in length, on the surface of which spangles of tinfoil are pasted in a spiral form, a small space being left between each spangle and the succeeding one. A spark transmitted along such a conductor appears at the same instant at all the intervals.

The luminous names, stars, and other figures are made on the same principle; they are formed by pasting strips of tinfoil, having breaks in its continuity at the proper places, on a square of glass, along which a spark is sent from the prime conductor.

2.) *The spangled pane* is merely a Franklin's plate (§ 487.), one of whose coats is cut up in small squares. When the plate is being charged, sparks fly in various directions, somewhat like lightning, between the squares of tinfoil; this is owing to the induction of the electricity. When the plate is discharged, the rays from the point where the discharge is effected shoot out like the solar rays.

A *spangled jar* is made by pasting the outer coating in a similar manner, of distinct pieces of tinfoil.

If the spangles be alternately of gold and silver leaf, the sparks will have all the colours of the rainbow.

3.) *The electrical aurora borealis.*—Procure a glass tube, two or three inches wide and a foot or two in length, and close its ends perfectly air-tight with brass caps. A pointed wire should be fixed in the interior surface of each cap; on the outside of one of them there should be a knob, but the other should have a communication closed by a valve, contrived so that it may be fitted on to the plate of an air pump and the air within the tube be exhausted. Connect the knob of the one cap by a chain with the conductor of the electrical machine; and if the tube be set in a vertical position, with that knob uppermost, when the machine is worked there will be a vivid representation of the northern lights, modified according to the degree of rarefaction attained by the air within the tube. If the exhaustion is nearly perfect, the whole length of the tube will be of one violet red colour; if a small quantity of air be admitted, luminous flashes will be alternately emitted from the points fixed to the inside of the caps. As more and more air is admitted, the flashes, which glide in a serpentine manner down the interior of the glass, will become thinner and paler, until at last the electricity ceases to flow through the column of air, when there will be merely a glimmer about the points of the wires. A similar phenomenon may be observed in the Torricellian vacuum of a barometer, if the electricity be excited in the interior surface of the glass by continued agitation of the mercury.

§ 494.

IV. A *phosphorescent light* is emitted by passing a discharge over the surface of many imperfect conductors, especially of such as belong to the mineral kingdom. Opaque bodies, and particularly fruits, are rendered luminous for a short time during the passage of a charge through them.

Expts. 1.) The following substances are rendered phosphorescent for some time by the transmission of an electric spark through them; they acquire various colours, viz.: —

White chalk, phosphorescent, orange.
Rock-crystal, at first red, then white.
Sulphate of barytes, bright green.
Calcined oyster shells, the prismatic colours.
Ditto, with sulphur, a steady bright light.
Amber acid, green.
Loaf sugar, green.

Henley's universal discharger will be found extremely convenient for performing these experiments. The substance through which you wish to pass the charge is to be laid on the stand between the wires *a a*, *fig.* 164., connecting them at the same time with a Lane's jar, *fig.* 162., having a surface of a square foot, or a foot and a half. These two pieces of apparatus will be found of great service in the following experiments: —

2.) Place a small melon, citron, apple, or any similar fruit, on the stand of the discharger; arrange the wires so that their ends are not far asunder, and at the moment when the jar is discharged the fruit becomes transparent and luminous.

One or more eggs may be treated in the same manner, if a small wooden ledge be so contrived that their ends may just touch, and the spark can be sent through them all.

Send a charge through a lump of pipe-clay, a stick of brimstone, or a glass of water, or any coloured liquid, and the entire mass of the substance will for a short time be rendered luminous.

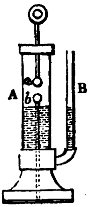
As the phosphorescent appearance induced is by no means powerful, it will be necessary that these experiments should be performed in a dark room; and indeed the effect of the other luminous electrical phenomena will be heightened by darkening the room.

§ 495.

V. *Mechanical effects of the condensed spark discharged from a Leyden jar, or an electrical battery.* — The electric current exerts a considerable mechanical force, in its passage to a good conductor, through such bodies as are either-non-conductors, or bad conductors of electricity, expanding, splitting, piercing, or dispersing them. If these bodies are liquids, as air or water, their particles are thrust aside; and if contained in vessels, the effect produced is the same as if they had suffered a momentary expansion.

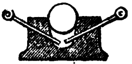
Expts. 1.) *Kinnersley's electrical thermometer* (*fig.* 170.) is well adapted to show the momentary expansion of the air when penetrated by an electric charge. The glass tube, A, is air-tight; it communicates with B, which is open at top; a coloured liquid stands at an equal height in the two tubes. When a spark passes from *a* to *b*, the liquid in B will be seen to rise for an instant.

Fig. 170.



2.) Close the aperture in a small wooden vessel, by inserting a cork or a piece of wood that fits exactly; let there be two wires passed through, whose points are about a quarter of an inch asunder; transmit a charge along them, and the cork will be forcibly projected.

Fig. 171.

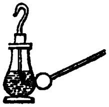


3.) Fill up the cavity of the little cup, mentioned in the preceding experiment, with sand or gunpowder, and the passage of the spark will be found to disperse the latter in all directions.

4.) Water suffers so sudden an expansion that the stoutest tubes are burst if filled with it, and a spark is transmitted through the tube, from a wire at one end, to a similar wire almost meeting it from the other end.

5.) Place several cards together between the knobs of a universal discharger, along the wires of which send a charge from a jar presenting a surface of not less than one square foot; if the charge be pretty strong, the spark will pierce through all the cards, which, if held to the nose, will be found to have a peculiar odour of sulphur and phosphorus, like that which may be perceived in places for some little time after they have been struck with lightning. Wood and other imperfect conductors may be penetrated in a like manner. Lay a piece of writing paper on the stage of the universal discharger, placing its knobs on the paper at a distance of one or two inches from each other; then transmit the charge, and if the paper was dry, it will be found to have been torn asunder by the passage of the spark.

Fig. 172.



6.) Fill a small vial with oil, close it with a cork, through which a wire passes, the lower end of it being so bent as to touch the inner surface of the glass. The other extremity of the wire, which projects above the cork, is formed into a hook, that the bottle may be suspended from the prime conductor. Set the machine in motion, and hold a metal ball opposite to that part of the vial which is touched by the wire within, and the spark, in its passage through the glass, will make a hole.

7.) Lay a piece of tinfoil, in which there are several holes, between two small boards, or two panes of glass; screw them tightly together, and transmit a pretty strong charge through the metal. On releasing the boards, or the pieces of glass, they will be found to be split.

§ 496.

VI. *Excitation of heat by the electric current.*—This is shown equally when the current is transmitted through fine wires and when a spark passes through any combustible substance. In the first case the effect is generally greater, the greater the resistance offered by the wire, and the more powerful the charge given off from the jar or battery; in the second, the effect depends principally on the readiness with which the body is put in a state of combustion, as many substances are ignited by feeble sparks, whilst others can be burned only by powerful ones.

Expts. Stretch a piece of very fine harpsichord wire between the arms of a universal discharger; if your battery is strong enough, you may use a piece of watch-spring. Send a powerful charge through the metal, and it will be either raised to a state of incandescence, or it will be melted. If the charge is not sufficient to fuse the wire, the increase in its temperature will be marked by its becoming blue.

If the wire be the same, the length of it fused by any particular charge will depend on the surface of the battery and on the intensity of the charge; that is to say, on the quantity and density of the electricity set in motion *: equal charges will therefore melt equal lengths of the same wire. In wires of different metals but equal diameters the length varies, and the better conductor any body is, the shorter the length that will be melted. Priestley and V. Marum tried by this means to ascertain the different conducting powers of different metals, but the results they obtained are deficient in accuracy. More recently Riess has performed some very exact experiments, by which he measured the temperature of a piece of platinum wire, forming part of the electrical circuit, with a very delicate electrical air thermometer that he constructed for the purpose. The principal laws which he founded on the results thus obtained are the following: — 1.) The increase of temperature in the wire through which the charge was sent is, other things being equal, proportional to the quantity and intensity of the electricity. 2.) If the wires of the same metal have different thicknesses, then the increase in their temperatures will be inversely as the biquadrates of their radii, their lengths being equal. 3.) The quantity of heat liberated in a wire by any particular charge is directly as the length, and inversely as the transverse section of the wire. 4.) The increase of temperature of any wire forming part of an electric circuit, is inversely as the duration of the discharge. 5.) In different wires connected together, through which a battery is simultaneously discharged, the quantity of heat developed is proportional to the retarding powers which these wires singly exert on any electric discharge.

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* A Lane's jar, having a surface of tinfoil of 9 Vienna square feet, = 9·68 English, was so powerfully charged by 14 turns of Pfister's plate machine (§ 484.), that its spark melted a piece of steel wire, No. 12., 18 inches in length; and V. Marum's great battery, of 550 square feet, fused an iron wire $\frac{1}{40}$th of an inch thick, and $24\frac{1}{2}$ inches long, throwing it off in little red hot globules.

2.) Very fine silver wire, if placed between the points of the universal discharger, burns with a greenish light, and passes off in a greyish smoke, if a tolerably strong charge be transmitted through it. The like may be done with fine wires of the other metals. If the wire be placed in a glass tube, you will be able to collect the oxides of the various metals, which will show their distinctive colours.

3.) Stretch a silk thread covered with silver, between the arms of the discharger, send through it a charge from the battery, the silver will be destroyed and the silk will remain uninjured.

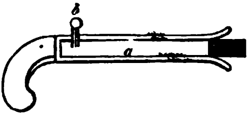
4.) Lay a strip of pure leaf gold between two sheets of paper, place them on the stage of the discharger, send a charge from a jar presenting a metallic surface of from 1 to 2 square feet through it, and the gold will be burnt. If the metal was chemically pure, there would remain a stripe of oxide of gold of a purple colour on both the pieces of paper; if it contained a portion of silver, the stripe would have a greyish tinge. A strip of pure leaf silver, burnt in like manner, would have left a grey mark of the oxide of silver.

5.) Lay a small piece of gold leaf between two little squares of glass, proceed in the same way as before, and the metal will be melted into the glass, which if viewed in reflected light will appear gilded in the spots to which the gold adheres, but if seen in transmitted light, the spots will have the colour of the oxide of gold. If you wish to preserve the glass from being broken, use three panes, laying the gold leaf between the uppermost and the undermost, and the middle pane will be uninjured by the performance of the experiment. A strip of gold-leaf, 1½ lines in width and 20 inches in length, was consumed by a spark from the conductor of V. Marum's machine; and a similar spark from Pfister's machine, to which we have already referred in the first experiment, burnt a strip of gold leaf ¼ of an inch wide, and 10 inches long.

6.) Of all substances that can be destroyed by fire, detonating silver is the most combustible. A small quantity of it, laid on the point of a knife, explodes instantly when held at a distance of several feet from the prime conductor of a machine in full play.

7.) The explosion of oxyhydrogen gas may be effected with almost equal ease, as a single spark is sufficient for the purpose. The apparatus generally used is an *electrical pistol* or *cannon* (*fig.* 173.); *a* is a metal tube, closed at one end; a copper wire *b*, insulated by its being contained in a glass tube, is carried through, so that the knob at its end is about ¼ of an inch from the opposite inner surface of the barrel. Now, hold the mouth of the pistol over a stream of hydrogen from a gasometer (*fig.* 128. Vol. I.), close the mouth of the pistol with a cork, send a spark on *b*, and the cork will be discharged with a loud report.

Fig. 173.



8.) Fill with cold water a wine glass, whose outer surface is perfectly free from moisture; pour on the top of the water a thin film of sulphuric æther, and connect the water by means of a chain with the prime conductor. Turn the machine round, and present your knuckle, or any other conductor, to the surface of the æther, and the spark in its passage from the water to the conducting body will ignite the æther. — Or, let any person stand on the insulating stool, and laying one hand on the prime conductor let him hold a metal spoon containing some æther in the other; let some one else present any conducting body to the spoon, and the passage of the spark will cause the æther to burst into a flame.

9.) Sprinkle some finely pulverised colophony on the surface of some water in an earthenware saucer, which is to be placed on the stage of the universal discharger, and its knobs placed at a distance of from 2 to 4 inches asunder; then transmit a charge from a Leyden jar, and the spark in its passage from one ball to the other will ignite the resinous powder. The same effect will follow, if the colophony be sprinkled on a rough board, or on a hank of cotton.

10.) The igniting power of a condensed spark is increased by sending it through a damp conductor. Hence we are enabled to ignite gunpowder, which resists the action of the spark under ordinary circumstances. (See *Third Expt.* § 495.) Place some gunpowder in the little wooden cup (*fig.* 171.), and carry the spark along a moist thread 6 or 7 inches in length, attached to that arm of the universal discharger which is connected with the negative coat of the jar containing the charge, and the spark in its passage from the end of one wire to that of the other will cause the powder to explode.

§ 497.

VII. *The magnetic effects* of the electric current are variously displayed; but, as has been already (§ 488.) remarked, the influence exerted by the interrupted and momentary currents of frictional electricity is less perceptible than that of the continued current, generated by electricity by contact, and by thermo-electricity. Its most remarkable feature is the excitation of magnetism in unmagnetized steel, and its inversion of the poles in magnets. A few experiments illustrative of these properties will now be given: —

Expts. 1.) Place a strip of copper-plate, about 1 or 2 inches in length, between the arms of the universal discharger; transversely to it, and supported by any insulator, lay a fine sewing needle, and pass through it some pretty strong charges from a jar. The needle will have become magnetic, that end which lay to the right of the electric current being a north pole, and the opposite end a south pole. Place the needle beneath the copper, and the needle's polarity will be reversed.

2.) Place a small variation needle on the strip of copper, so that the latter shall intersect its magnetic meridian at right angles; send some powerful charges through it, from west to east, and the magnet's polarity will be reversed: this effect will not obtain if the charges are transmitted from east to west.

3.) Steel needles may be magnetized with greater certainty, if the electric current be insulated and conveyed by a helix around the needle. This will be best effected by placing the needle in a spiral of copper wire covered over with silk, the ends of the helix are to be in contact with the arms of the discharger. The single spark from the prime conductor exerts a sensible effect; but if a charge be sent from a loaded jar, the magnetism will be still stronger. Lay a magnetized needle in the helix, and conduct the electric current, so that the north pole of the needle shall lie on the right hand of the direction in which the current moves; and after a few charges the needle's pole will be reversed.

An explanation of this phenomenon will be given in the section on Electro-magnetism.

§ 498.

VIII. Its *physiological effects* are developed by electricity when in a state of tension: they appear to be owing, in part at least, to the induction of electricity taking place in the human frame. Among those effects may be enumerated the sensation of a spider's web being drawn across the face, and the emission of phosphoric odour. They are felt most powerfully in those parts of the body which form a part of the circuit through which the electric current passes, by a shuddering sensation, and a contraction of the nerves and muscles, known as the electric shock.

The effects of the shock vary with the extent of the surface covered with tinfoil, and they may become so intense as to cause transient or permanent lameness in particular limbs, nay, even death itself. In performing these experiments, care should be taken that the charge is not too strong. — The discharge from a single jar is sufficient to kill small animals; and a battery of 13 feet coating is enough to stun or even to destroy life in a large animal, especially if the stroke be conducted through the skull.

The conduction of the successive and momentary currents through parts of the animal organization produces a contraction of the nerves and muscles, by which the activity of the vascular system is increased, the motion of the fluids accelerated, and the animal heat raised. Hence frictional electricity has been frequently applied in medical practice.

Electricity produces on vegetables, effects closely resembling those just described in the case of animals: conduction appears to exert no perceptible influence on vegetation; but if a charge from a jar be sent through plants it proves fatal to them.

Expts. 1.) *The electrical bath* is administered by placing a person on an insulating stool, and directing the electric current from the conductor to different parts of the body by means of some pointed conductor.

2.) *The electric shock* from a charged jar may be given to a number of individuals at once, if they lay hold of each other's hands, the last person in the circle putting himself in contact with the outer coat of the jar, and the first touching the knob of the jar, by which means the circuit will be completed. On account of the velocity with which it travels the shock will be experienced simultaneously by all. — Interpose in some part of the circuit a moistened conductor, as, *ex. gr.*, a piece of wet rope; and instead of the shock, there will be merely a tingling sensation felt in the tips of the fingers.

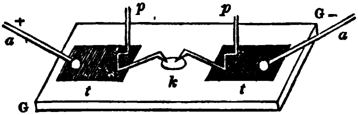
3.) A mouse, bird, or fish may be killed by placing its head between the wires of the universal discharger, and sending a powerful shock through it. The effects of the electric shock will be visible in fishes if they are merely placed in a glass of water, and the charge be transmitted through the liquid.

§ 499.

IX. *Chemical influence of the electric current.* Unless the preceding experiments on the combustion of the metals be included under oxidation, the chemical effects of the electric current are scarcely perceptible on account of its intermittent character, and the impulsive nature of its action. (§ 488.) The following experiments may, however, serve to show that it really possesses a decomposing power: —

Expts. 1.) Faraday has proved, beyond doubt, that many substances may be decomposed by means of the electric current, obtained from an electrical machine in full work: the plan he adopted was the following: — Lay two pieces of tinfoil (*t t*, *fig.* 174.) on a pane of glass GG; from each piece of tinfoil projects a platinum wire, bent upwards from the glass, like *p*, in such a manner that there shall be a small space between the two points where they touch the glass: on this space the body *k* is placed, which it is proposed shall be decomposed. Place the glass on the stage of the universal discharger, putting its two wires *a* on the tinfoil, and connect one of them by a chain and a moist thread with the prime conductor, and the other with the cushion of the machine. — If a drop of a solution of sulphate of copper be placed at *k* between the platinum points, after a few turns of the machine, the metallic copper will be deposited on the end of the negative wire. The neutral salts dyed with indigo gave a coloured deposit on the + wire; a solution of iodide of potassium gave a deposit of the iodine on the same wire. The decomposition is effected still more easily, if

Fig. 174.



instead of the liquid solutions we employ blotting paper saturated with any of the solutions. A piece of this test-paper saturated with a solution of sulphate of sodium, nitrate of potassium, or any other of the neutral salts, will deposit its acid on the + and its alkali on the — wire. Paper dipped in a solution of iodine in æther or spirits of wine will give a blue tinge of iodine on the — wire.

The decomposition of water by Wollaston and other philosophers, by means of minute platinum points inclosed in glass tubes, along which points the current is conveyed through the water with which the tubes are filled, is so extremely feeble that the least trace of the component elements does not make its appearance for a length of time. Faraday investigated the subject anew, without arriving at any satisfactory conclusion; he was, however, inclined to think, that when the current was unattended by any spark, the oxygen was set free at the + point, and the hydrogen at the — point of the wires, because he observed that the emission of gas at the latter was much stronger than at the former.

2.) Sparks discharged continuously through the air combine its elements so as to form nitric acid. Faraday discharged the electric sparks through the air above a strip of litmus paper, saturated with a solution of caustic potash. The paper was reddened, and on being dried it was found to be penetrated with saltpetre.

3.) From a fine metal point connected with the conductor of any electrical machine, let the + electricity for some time be run against the tongue, and a faint acid taste will be produced; if — electricity be sent upon it, an alkaline taste will be perceived.

§ 500.

As all the phenomena and effects caused by electricity excited by means of friction have now been explained, it is time to present the reader with a brief sketch of some of the opinions that have been entertained with regard to the sources whence this powerful agent is derived. Some have thought that it is mainly caused by the heat generated by rubbing the two bodies together. This can, however, at best be regarded as but a secondary source; since, otherwise, the quantity of electricity evolved would be in proportion to the heat excited, which is not the fact. More recently this view has been adopted, that the excitation of electricity is owing to some chemical process attending the friction. The existence of chemical agency has been inferred from the presence of the peculiar odour emitted during the friction, as also from the necessity that the amalgam applied to the cushions of the electrical machine should be a very oxidizable body. To this it may be objected, that it yet remains to be proved that this peculiar odour is necessarily connected with the development of electricity; and that the oxidation of the amalgam is not an indispensable requisite, has been shown by Sir H. Davy's experiments, for he found that a small electrical machine in an atmosphere of hydrogen, carbonic acid gas, and other gases, gave out as much electricity as when worked in the common air; indeed, in the carbonic acid gas it yielded more. According to a still more recent theory than the above, it has been held, that a peculiar motion in the molecules of the bodies rubbed together is the true source from which the electricity is derived. This hypothesis has as yet been but partially received, and the discovery of an explanation, both general and satisfactory in its application, is an object still to be desired.

Schönbein has performed a number of experiments, in order to detect the properties of the odour emitted during the action of an electrical machine (§ 485.), which, in the case of the cards penetrated by the spark, bears so striking a resemblance to the blasting of objects by lightning. (*Fifth Expt.* § 495.) This philosopher thought that he could recognize the odour in the decomposition of water by the electric current. He accordingly gave it as his opinion, that this odorous principle, which he called *ozon*, was a body contained both in air and in water, that it had hitherto escaped the observation of chemists; and that, under certain circumstances, this element was set free by electricity. De la Rive, on the contrary, holds that this odour is caused by extremely minute metallic particles with which the electric fluid is charged; and which, when water is decomposed, are given off with the oxygen in the atmosphere.*

III. ELECTRICITY BY CONTACT, GALVANISM, VOLTAISM.

A. *Of the Electricity elicited by the Contact of Heterogeneous Bodies in general.*

§ 501.

The state of electrical quiescence in two heterogeneous bodies, which are good conductors of electricity, is destroyed by bringing them into contact with each other. Separate them in an insulated condition, and one will be found to be + electrified, and the other — ; but this state of tension is often so feeble that its existence can be proved only by the aid of a condenser.

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* Professor Schönbein read a paper on "Recent Experiments on Ozon," at the 15th meeting of the British Association in June last. From these experiments it appeared that the smell was always developed at the + pole; that it was capable of being preserved in closed bottles; that heat destroyed it; and that many of the metals had also the same power. Although at first supposed to be an elementary body, it may now be looked upon as, in all probability, a trit-oxide of hydrogen. An analysis of the professor's paper may be found in the Athenæum for July 6. 1845.

Volta, towards the end of the last century, first discovered this peculiar excitation of electricity in the metals. *Volta's fundamental experiment,* by which the existence of this species of electricity may be verified, can be variously performed.

First Expt. by means of the condenser. Place in immediate contact two polished discs, one of copper, the other of zinc, holding them by means of glass handles, so that they may be insulated; separate them, and convey the sensible electricity of one of the plates to a condenser. (§ 489.) Touch both the plates with the hand so as to carry off their electricities: repeat the contact and separation, and, as before, convey the electricity of the one plate to the condenser. Repeat this eight or ten times until you have sufficiently charged the condenser, which will be loaded with + electricity, if you have touched it with the zinc plate, or with — electricity if with the copper one. The electricity thus accumulated by conduction on the condenser, may be tested by means of a delicate electroscope. To avoid exciting electricity by touching the metal of the conductor with the plate, which would affect the accuracy of the experiment, as we profess to obtain the electricity merely by the contact of the zinc and copper discs, a piece of moistened blotting paper should be laid on the plate of the conductor, and the disc should be made to touch this paper, and not the metal of the conductor itself; or the condenser, may be furnished with two plates, one of zinc and the other of copper, and when the electricity is conveyed to the condenser, these should be changed, so that the like metals should always be brought together. Peclet's double condenser will still more effectually secure this object. (§ 489.)

Second Expt. without the condenser. Screw a perfectly smooth plate of pure copper, about 2¼ or 3 inches in diameter, on to the conductor of a Becquerel's electroscope, or of a delicate Oersted's electrometer. Now, on it lay a similar disc of pure zinc, of exactly the same size, and the two plates will, by contact, be oppositely electrified. While this contact is maintained, the ± electricities will be held in a latent state. Remove the zinc plate by a glass stem, which insures its being insulated, raising it perpendicularly from the copper one, and the electroscopic bodies will show that the copper plate is negatively electrified. The + electricity of the zinc plate will be verified by presenting it to another electroscope standing near the former; or, without a second electroscope, deprive the copper plate of its — electricity; touch it with the edge of the zinc plate, that the — electricity again excited in the copper may not affect the indices. Or the entire surfaces may be put in contact, the zinc plate being allowed to lie on the copper one.

Now screw a zinc plate on the conductor of the electroscope, and place the copper plate on it, the former will in this case be + electrified when the copper is removed; and in like manner, as before, the electricity rendered sensible in the copper may be tested.

Although the phenomena of contact electricity are so numerous, and effects so varied in their nature derive their origin from it, yet it remained long unknown to philosophers, even after they had pretty thoroughly investigated the phenomena of electricity by friction. This was owing principally to the fact, that it acts so feebly as not to be very readily detected. As on many other occasions, a happy accident, with regard to this branch of science, led to an important discovery, which stimulated to that further research that has conducted to some of the brightest and most eventful discoveries of modern times. Professor Galvani, of Bologna, observed in 1797, that when he touched a nerve and muscle in the leg of a dead frog with two different metals, on bringing these into contact the leg moved convulsively. The author of this discovery considered this as the effect of a peculiar power exerted on the animal organization: he therefore gave to it the name of *animal electricity;* and even to the present day, out of respect to the discoverer, it is frequently called *galvanic electricity*, or *galvanism.* Volta soon after proved, by means of the condenser he had lately invented, that this electricity by no means resided as an extraordinary agent in the animal organization, but that it was the consequence of two metals being brought into contact, and that the nerves and muscles merely exhibited the sensible electricity, as any other delicate electroscope would. This theory led him to the most important discoveries, and in the year 1800 to the construction of that valuable piece of apparatus known by the name of the *voltaic pile.*

§ 502.

The influence thus set at work in bodies was styled by Volta the *electromotive force*, and by this appellation it is still known: the bodies, by whose mutual contact it is elicited, are termed *electromotors.*

The intensity and species of electricity which each of such bodies acquires when variously combined is by no means uniform.

According to experiments performed by men of science for ascertaining this point, it has been found that the electromotors taken as a whole may be arranged in order, so that the first in the list will be + with any of the others which are ranged after it in the list, and that they are — ; that beginning at the other end of the series, the last substance will be — , and any of the preceding with which it may be taken will be + electrified; and that all the intermediate electromotors may be either + or — electrified; and that, if taken in pairs, that which stands higher on the list will be + when joined with any lower in the list, which will be — electrified; lastly, that the difference of tension excited by bringing these bodies in contact is greater the farther apart they are in the series. The list thus constructed forms a *table of electromotive tensions*, as ascertained by the use of a condenser and a delicate electrometer. Below we have given four such tables, compiled by different philosophers.

Volta.

+ Zinc, lead, tin, iron, copper, silver, graphite, different kinds of charcoal, crystallized amber.

Pfaff.

+ Zinc, lead, cadmium, tin, iron, bismuth, cobalt, arsenic, copper, antimony, platinum, gold, mercury, silver, charcoal, argentum vitreum (vitreous silver ore), sulphurous pyrites, cuprum mineralisatum pyritaceum (yellow copper ore), galena, crystallized tin, niccolum sulphuratum arsenicum pyritaceum (arsenical mundick), molybdœna, protoxide of uranium, oxide of titanium, graphite, wolfram (tungstate of iron and manganese), gypsum stillatium, crystallized amber, peroxide of lead (?).

Henrici.

+ Zinc, lead, tin, antimony, bismuth, iron, brass, copper, silver, mercury, gold, platinum.

Peclet.

+ Zinc, lead, tin, bismuth, antimony, iron, copper, silver, gold, platinum.

Their respective degree of tension is, however, considerably modified by the elevation of their temperature, the degree of polish on the surface of the metals, still more by the addition of foreign ingredients even in minute quantities. Zinc is rendered much more positive by amalgamation.

These experiments may be satisfactorily performed even without a condenser, if a Becquerel's electroscope is at hand;

or, better still, a delicate electrometer on Oersted's construction. (§ 480.) The deviation of the needle in the last named instrument enables us with tolerable accuracy to compare the difference in the electromotive tension of any two bodies. The metals to be subjected to this test should be of a circular form, from 2 to 3 inches in diameter, and at least 2 lines thick. As silver, gold, and platinum plates of this size would be very expensive, brass plates may be used instead, covered with gold, silver, or platinum, by the process of electroplating. (§ 519.) A circular hole is made in the centre of each of these discs, for the purpose of connecting them with the conductor of the electrometer, or for inserting glass stems by which they may be insulated. The plates must be as highly polished as possible, and the metal should be perfectly pure. The zinc or platinum plate, as being the extremes in the table, is to be screwed to the conductor of the electrometer, and the others are to be brought into contact with it in the manner described in the second experiment of the preceding paragraph. To investigate any two metals, say iron and silver, all that is requisite is to place one of them on the plate of the conductor, to insulate the other, and place it on the former.

If several different electromotors are brought into mutual contact at once, as *ex. gr.*, A with B and B with Z, then this remarkable result ensues, that whatever electromotor B may be, A always has the same kind of electricity, and of the same intensity, as if it had been in immediate contact with Z, without the interposition of B. Further, if instead of B we interpose any number whatever of opposite or similar electromotors between A and Z, as A, B, C, D . . . Z, A continues in this case also to be electrified precisely as if it were in immediate contact with Z.

For the sake of illustration, we will suppose the relative difference of tension between A and B = 5, between B and C = 1, between C and D = 3, between D and Z = 7; then the difference of tension between any two members of the series is invariably equal to the sum of the differences of the intermediate links. Hence, between A and C $5+1=6$, between C and Z $=3+7=10$, and between A and Z $=5+1+3+7=16$.

§ 503.

The electromotive force can, moreover, be excited not only between the solid conductors of electricity, but also between them and conducting liquids. With respect to the species of electricity excited by the contact of the various metals with different liquid bodies, the numerous experiments of Pfaff have conducted us to the following results:—

1.) *The alkaline liquids*, as caustic potash, caustic soda, ammonia, generally excite in the metals a state of *negative electrical tension*, the intensity of which is greater the nearer the metal is to the positive end of the series. To this rule, however, there are some exceptions. When in contact with these liquids, tin, antimony, zinc are the most powerful; platinum, bismuth, silver, the most feeble electromotors.

2.) *Concentrated acids*, as nitric acid, sulphuric acid, &c., impart to metals the opposite, that is to say, the *positively electrical tension*; and in particular *all the metals*, without exception, when acted on by concentrated nitric acid, become *positive*. In this acid, steel, cast iron, pure iron, and platinum are the most powerful electromotors, and zinc the feeblest. With sulphuric acid they are divided into two classes; those metals, as gold, platinum, copper, which stand near the negative end of the series, becoming *positive*; the others, antimony, tin, and zinc, being *negatively* electrified. The same rule holds good with regard to hydrochloric acid.

3.) *In diluted acids and solutions of heavy metallic salts*, the character of the electrical tension for the most part depends on the order of the metals in the series. Considered as a whole, they are *negatively electrical* towards these liquids, the more positive metals being the most intensely negative, the negative ones less negative, showing an increasing tendency to become positive; and those which are the most negative when acted on by these liquids actually acquire a positive tension. The *solutions of an alkali with sulphuric acid* present the striking anomaly of rendering the negative metals *most powerfully negative*.

From a consideration of these facts it was inferred, that the liquids received exactly the opposite electricity to that acquired by the metals immersed in them, and that the intensity of their tensions corresponded.

4.) In most of the liquids, the metals, as a whole, invariably display the like excitation, but the original difference in the tension of those whose surfaces are chemically acted on by the fluids decreases, and is at length converted into the opposite kind to that which they had at first.

> Pfaff, to whom the scientific world is under considerable obligations, modified in various ways the experiments which led to the results we have just developed: *ex. gr.* he procured strips of the different metals, and laid on them similar pieces of pasteboard saturated with the liquid he wished to examine, and connected the metal with the collecting plate of the condenser by laying under it a piece of blotting-paper soaked in distilled water, the upper strip of pasteboard being

connected with the ground. Then he procured a number of little tubes shaped like a V; these he filled with the liquid, and in one leg he put the strip of metal, in the other a little bit of wood or paper, and connected first one of these bodies and then the other with the condenser, taking care always that a connection should be established between the other body and the ground.

It has been ascertained further, that fluids act on each other in a manner precisely similar to that in which they affect metals, or in which the latter affect each other when in contact; that this obtains not merely with regard to such as exert any chemical influence on each other, but also in such as are chemically indifferent; whence it has been inferred, that these bodies also may be arranged in a series with regard to their electrical tension. The difference of tension, however, between heterogeneous liquids is so small, that its existence is deduced only from the electrical current which is generated. Professor Fechner, who has distinguished himself by his investigations as to the theory of electrical phenomena, first established the existence of this electrical action by a series of experiments, from which he had removed every other disturbing cause.

§ 504.

From what has been just advanced it follows, that the metals by contact with different liquids sustain a change in their relative electromotive powers; that this change is not equally great in all metals; and that it depends, in great measure, on the nature of the fluid itself. Hence Martens thinks we may infer that liquids are not properly electromotors, but rather modifiers of the electromotive force of the metals immersed in them; so that their influence may be regarded as at one time increasing, and at another weakening the electrical tension, according as they act upon two metals, in the same manner as the contact of the metals, or in an opposite one to it.

If, now, it be asked, what is it that causes these modifications, it appears invariably that those fluids which exert the most powerful chemical influence on the metals are in general the most influential in modifying their electromotive properties. It is also true, that the mere contact of a liquid unaccompanied by any chemical change is sufficient materially to affect the electromotive state of a metal.

Berzelius has noticed that a similar influence is exerted by establishing a contact between many of the metals with a gas. This is especially the case with platinum, which by hydrogen is positively electrified, by bromine and chlorine negatively.

The electromotive tendency developed by such contact seems in some metals to increase the longer it lasts, and even to reside for some time in operation after the exciting cause by which it was induced ceases to act. This altered electromotive state of the metals is called their *electrical polarization.* The metals which become most powerfully polarized by contact with certain liquids are iron and platinum. When immersed in alkaline solutions, they become increasingly positive the longer the contact is maintained; platinum becomes polarized when its surface in contact with the liquid becomes coated with hydrogen; or, as we have already remarked, it may be polarized by immersion for a length of time in this gas.

Iron, immersed in some liquids, possesses a very remarkable property; for, if it be placed in some of the dilute acids, it acquires an electromotive tension answering to its place in the series; but when immersed in concentrated nitric acid, and according to Martens, in acetic acid or alcohol, if combined with platinum, it becomes almost as powerfully electrical as that metal. Thus iron changes its chemical relation to many liquids; as after polarization, *ex. gr.*, it will no longer be acted on by dilute nitric acid, nor will it decompose solutions of copper; in short, it will become as perfectly indifferent as the noble metals. (§ 72.) Schönbein, who has investigated this subject thoroughly, calls iron under these circumstances *passive.*

B. *Different Kinds of Hydro-electric Batteries.*

§ 505.

When two heterogeneous metals are made to touch the same liquid, which may be done either by placing strips of the metals in a vessel containing the liquid, or by soaking pieces of cloth or brown paper in it, and interposing them between plates of the two metals; in either case both the metals will be in a state of electrical tension, but of unequal intensities, the more powerful electromotor being in the greater state of tension. This difference in their tensions will be the more considerable the wider asunder the metals are in the electrical series as regards the particular liquid in which they are immersed. Connect the more powerful electromotor with the ground, and the weaker metal acquires the opposite electrical tension, as may be seen by applying that end of it which projects out of the liquid to the condensing plate. This may be at once shown by immersing copper, silver, or platinum in dilute acid, or saline solutions with either tin or lead, but especially with zinc; the copper, silver, or platinum will become positively electrical, while the tin, lead, or zinc will continue negatively so. The positive tension in this case answers to the difference of the negative tensions subsisting between the immersed metals. Next, connect the more feeble electrical metal with the ground, test the other by the condenser, and it will be found to retain its original electricity, though in a less degree, and with an intensity corresponding precisely with the difference of the electromotive tensions of the two metals. (§ 503. 3.) (a) Immerse two strips of the same metal in a liquid, and both will be equally electrified; no difference will exist between their tensions. (b) But if the fluid polarize the metal placed in it, we shall obtain an effective battery with a single metal, by immersing one of the plates before the other, as is done, for instance, when iron and platinum are brought in contact with a solution of caustic potash. In proportion as the polarization of the second plate proceeds, the difference in the tensions of it and the plate first immersed diminishes, until after some time it ceases altogether. The difference in the tensions of any two metals will be increased, for obvious reasons, if the liquid in which they are plunged excites in one a condition of positive, and in the other of negative electrical tension, as happens when zinc and copper are immersed in concentrated sulphuric acid. (§ 503. 2.) *Fig.* 175. represents an arrangement of this kind, both copper (C) and (Z) being immersed in the acid (S_3). For similar reasons, an opposite electrical tension will be produced if two homogeneous metals be connected together, and placed in two different electromotive fluids, the metal in the one being negatively electrified, and that in the other positively. As an illustration, we may immerse one piece of platinum in an alkaline solution, and another in concentrated nitric acid; or immerse two plates of iron, one in sulphuric acid, and the other in concentrated nitric acid. (c) (§ 503. 1 and 2.) A scheme of this is given in *fig.* 176., (P*t*) being the platinum, (A) the alkali, (*a c*) the acid, and *a b* the porous material between the liquids. The most intense electromotive tension is excited by employing two heterogeneous metals and two similar liquids, the one metal being immersed in that fluid which renders it the most powerfully negative, and the other in that which renders it the most powerfully positive, the fluids themselves being connected by interposing a porous partition betwen them. Such a

Fig. 175.

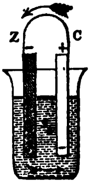


Fig. 176.

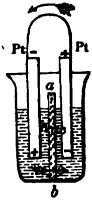
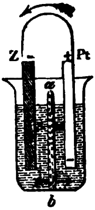


Fig. 177.



combination is effected thus, as shown in *fig.* 177., by placing platinum (P*t*) in concentrated nitric acid (N_5), and zinc (Z) in concentrated sulphuric acid (S_3). (d)

(a.) Suppose copper and zinc were placed together in a dilute acid, and that the zinc, as the more powerful electromotor, acquired a tension of -3, whilst the copper was merely -1, the difference between their tensions would therefore be $=2$. Connect the zinc with the ground, and the copper would show on the condenser a tension of $+3-1=+2$; if the copper be similarly connected, the tension of the zinc will be $+1-3=-2$.

(b.) Immerse two strips of zinc or copper in the same acid, and the maximum tension of each strip of zinc will be -3; that of each strip of copper -1, the difference of tension in either case $+3-3$, or $+1-1=$ nil

(c.) Now immerse a plate of iron in sulphuric acid and another in concentrated nitric acid; then the former will have a negative tension, say of -2, and the other a positive one of about $+4$; the difference of the tensions between these two homogeneous metals will $=6$. Let there be a conducting medium between the two fluids, connect the iron in the nitric acid with the condenser, and the plate which is in the sulphuric acid with the ground; then the former acquires a positive tension of $+4+2=+6$; reverse the arrangement, and the iron in the sulphuric acid acquires one of $-2-4=-6$.

(d.) In like manner we obtain the tension resulting from a combination of two heterogeneous electromotors with two different liquids, as *ex. gr.* of zinc with sulphuric acid and of platinum with nitric acid. If in the case supposed the tension of the zinc be -3, and that of the platinum $+5$, then the difference of their tensions is 8; connect the zinc with the ground, and the platinum will have a positive tension of $5+3=+8$; and if the platinum be so connected, then the zinc will have a negative tension of $-3-5=-8$. These batteries may, however, be so combined, that the two heterogeneous electromotors may acquire a similar and equal tension from the liquids in which they stand. In such a case the tension of each electromotor equals the difference between their tensions, viz. nil. This will happen if zinc be immersed in a dilute acid, and platinum in a solution of some alkali with sulphuric acid.

The difference in the tensions of the electromotors immersed in a fluid has been explained by assuming that the electricity originally excited in each by contact with the fluid acts by induction or polarization on the particles of the fluid lying between the two plates in such a manner that every such particle acquires an equally intense electricity, but of an opposite character to that of the metal on the side nearest to each of the metals; while on the side more remote it acquires a similar and equal electricity to theirs, so that the ends of the circuit formed by the liquid which touch the other metallic surfaces excite the opposite electrical tension or polarization. A reference to *fig.* 178. will render this more easy to be understood than a long verbal description.

Fig. 178.

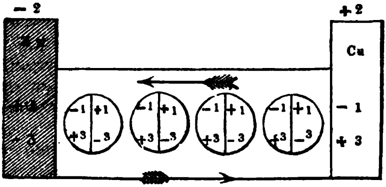
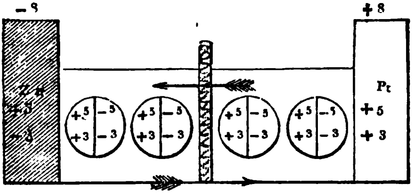


Fig. 179.



Z *n* is a zinc and C *u* a copper plate, connected in a circuit by the particles of the fluid. Now suppose the tension excited by the fluid on the zinc alone were − 3, then the polarization produced in the liquid by this metal would be expressed by the lower row of numbers contained in the circles representing the particles of the liquid; and if the tension it would have caused in the copper alone be − 1, then the upper numbers will mark its polarization by this metal, and the result of this double induction of electricity would be that the tension of the zinc would be − 2, and that of the copper + 2. — *Fig.* 179. represents a similar combination of a zinc and platinum battery with sulphuric and nitric acid, the zinc acquiring the negative, and the platinum positive electricity.

Such combinations of solid electromotors with suitable liquids constitute *simple hydro-electric* or *voltaic batteries*. Of these there are three principal varieties.

1.) *Batteries consisting of two heterogeneous electromotors with one fluid.* — These were the earliest invented by Volta; and until lately they were almost the only ones in use. They are commonly made of zinc and copper plates immersed in either dilute acid, or some saline solution.

2.) *Batteries of one homogeneous metal with two heterogeneous liquids.* — To this class belongs Becquerel's hydro-electric battery, as it is called, in which platinum (see *fig.* 176.) is put in contact with a solution of caustic potash, or with concentrated sulphuric acid. Weber and Wöhler's batteries are also made on a similar principle, the same metal in the former of these being immersed in sulphuric, and in the latter in concentrated nitric acid. The difference of tension in a Becquerel's battery is far less than in one of class 1.) This instrument has served no other purpose than to establish the fact, that a state of electrical tension can be induced by contact with two heterogeneous fluids. The *iron battery* is much more effective, as the polarization of this metal in the concentrated nitric acid causes a very considerable degree of tension.

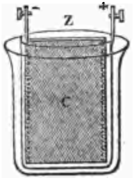
3.) *Batteries combined of two heterogeneous electromotors with two different liquids:* these are a recent discovery, and are the most effective of all the varieties; *i. e.* by means of them the maximum difference of tension between the electromotors is produced. Among this class we may name *Daniell's zinc and copper battery,* in which zinc stands in contact with sulphuric acid, and copper with a solution of sulphate of copper; *Grove's zinc and platinum; Sturgeon's zinc and iron;* and *Bunsen's zinc and carbon batteries,* in which the zinc is placed in contact with sulphuric acid, the platinum, iron, and carbon with concentrated nitric acid.

The construction of these batteries admits of various modifications; from which, indeed, the different names they bear are for the most part derived.

1.) *Single-fluid batteries.* *Volta's* battery consists of equal plates of copper and zinc, between which are laid pieces of flannel or paper of the same size, soaked in the exciting liquid.

In *Wollaston's* battery (*fig.* 180.) the zinc plate is surrounded by the copper one, which however does not immediately touch it at any point, there being a space of $\frac{1}{4}$ of an inch or thereabouts all round between the two. The two plates are to be immersed in the exciting fluid.

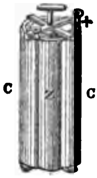
Fig. 180.



Oersted's trough apparatus is essentially the same with the preceding battery. It consists of a trough of copper plate, in the form of a parallelopiped, about ½ an inch wide at the bottom; in it the zinc plates are arranged so as not to touch the copper; the trough serves also to hold the liquid.

Hare's spiral battery (*fig.* 181.) consists of two zinc and copper plates of equal length, rolled together in a spiral form, so that they are about ¼ of an inch asunder. Their parallel position is given to the spirals by means of a wooden cross at top and bottom, with notches into which the plates are fastened. Both crosses have a common axis. There is a handle at top, and to each of the metal plates is attached a mercury cup + and —. This combination is then set in a glass cylinder large enough to receive it, in which the liquid is placed. This apparatus has one advantage, that metal plates of a considerable size can be used without their occupying much room.

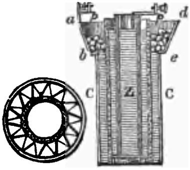
Fig. 181.



Faraday recommends, to ensure a powerful action of these batteries, the use of a mixture of 200 parts of water, 4½ parts of sulphuric acid, and 4 of nitric acid. If the effect is desired to be less violent but more permanent, he recommends a solution of common salt, or a mixture of sulphuric acid, with from 20 to 30 times its quantity of water. The electromotive power will be increased and rendered more constant by amalgamating the zinc, which can be accomplished most readily and cheaply in the following manner:—First, immerse the rough zinc plates in a weak solution of sulphuric acid, containing from 6 to 8 times as much water as acid, until the thin film of oxide is dissolved; then wash them with water and place them in a dilute solution of nitrate of mercury. After a short time there will be found on the surface a perfectly uniform amalgam of zinc; when this is formed, wash the plates with water and rub them with sawdust.

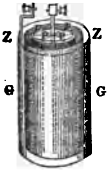
2.) *Batteries with two different liquids.* In these the two liquids must be so placed as to establish conduction without their being allowed to mix. This is best effected by interposing some porous substance between them; thin cylindrical cells of porous porcelain, slightly baked, answer best. Place a cell of this kind in a cylindrical glass, an inch or an inch and a half wider than it in diameter; in the earthen cell, place one electromotor with its appropriate liquid, and in the glass vessel the other with its liquid, taking care that the two electromotors are not more than from ⅛th to ¼th of an inch from the walls of the porcelain cell.

Fig. 182.



A sectional view is given in *fig.* 182. of the most advantageous arrangement of a Daniell's battery. c c is a copper cylinder with bottom, rather wider at top, as *a b* and *d e* show (the outer glass vessel is not required with this construction); *p p* is the porous porcelain cell, in which the amalgamated zinc cylinder stands. Pour a saturated solution of sulphate of copper into the copper cylinder. That the action of this battery may be constant, the strength of the solution must be maintained. For this purpose two concentric rings of copper wire connected together by zig-zag wires fit round the porcelain cell, and rest on *b* and *e* against the copper cylinder. On this net-work such a quantity of the copper crystals is to be laid, as by their gradually dissolving will maintain the liquid at its required strength, and so repair the waste caused by the working of the battery. If violent action is desired, use 1 part of concentrated sulphuric acid to from 4 to 9 parts of water; if moderate action, 1 part of sulphuric acid to from 50 to 100 of water.

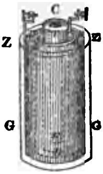
Fig. 183.



In *Grove's battery* (*fig.* 183.) the amalgamated zinc cylinder z z stands in a glass vessel; inside the zinc is placed the earthenware cell *pp*, intended to receive the platinum. Leaf platinum will be found the most convenient, and to save expense it may be had thin. To ensure at the same time a large surface of this metal, and action on both sides, Grüel's arrangement may be adopted. The leaf platinum is attached by means of wires of the same metal to a central stem, so as to form four or six flaps; the whole has one common conductor. Poggendorf recommends as a more simple contrivance, that the leaf of platinum be about half as broad again as the diameter of the porcelain cell into which it may be made to go by bending it in the form of an S. By this means, all cutting and fastening of the platinum will be dispensed with, except only fastening it to the wire which is to serve as the conductor. Pfaff employed a porcelain cylinder coated with platinum, instead of a leaf of this metal. This will be rather cheaper than the metal itself, but as far as my experience goes, these cylinders are less effective than an equal surface of platinum, and I have used the cells both from the manufactory at Copenhagen, and also from that at Meissen. The liquid used to act upon the zinc is sulphuric acid diluted with from 4 to 9 parts of water; that on the platinum, nitric acid whose specific gravity is 1·33.

In *Bunsen's battery*, charcoal is substituted for the expensive substance, platinum. For a length of time, attempts had been made to use for this purpose graphite (plumbago) in its natural state, and also the masses found in gas retorts; but the difficulty with which portions could be met with of sufficient size and of convenient form, imposed an insuperable obstacle. Professor Bunsen has, however, succeeded, by repeatedly heating a mixture of pulverized coal and coke, in obtaining a strong porous mass, which, as regards its conducting and electromotive powers, is fully equal to platinum; it can easily be worked and made to assume the required form. Bunsen has variously constructed his batteries; one of the simplest combinations, perhaps, is the following, which nearly resembles Grove's. (See *fig.* 184.) C is the carbon cylinder, substituted for one of platinum, standing in a porcelain cell *p p*, whose diameter is 3 or 4 lines longer than that of the carbon. *pp* is enclosed in an amalgamated zinc cylinder *z z*, whose diameter is about two lines greater than that of the earthenware cell. The whole is placed in a glass G G about an inch, or an inch and a half wider than the earthenware. Drill a hole *m n* in the carbon, to within an inch and a half of the bottom, and about one third of its diameter in width. Into this cavity concentrated sulphuric acid is to be poured, by which the porous mass will soon be penetrated. Fill the interval between the earthenware cell and the carbon cylinder with the same acid. A copper ring *r*, which fits the latter tightly, serves as a conductor. The zinc is acted on by sulphuric acid, with from 4 to 9 parts of water. Bunsen has since modified his battery, by making the carbon cylinder open at bottom, and of sufficient size to contain the earthenware cell in which he places the zinc element.

Fig. 184.



With equal surfaces, the powers of a platinum and carbon battery are nearly equal. They are both far superior to a Daniell's constant battery. Jacobi says 6 square inches of platinum in a Grove's battery are equal to 100 inches of copper in a Daniell's battery. According to my own experiments I found, that to produce equal effects, it required 16 times as great a surface of copper as of platinum; and in a spiral battery, on Hare's construction, I found 340 times the surface of copper was needed to that of platinum to insure equal effects.*

Now, although Grove's and Bunsen's batteries are more powerful than Daniell's, yet the latter has this advantage over them, that its action is the most constant, its electromotive force being but little impaired by the battery's being kept at work for a whole day. There is this additional inconvenience connected with the use of both the platinum and carbon batteries, that the nitric acid used in them, in proportion as it is concentrated, becomes converted the more rapidly and profusely into nitrous acid, the vapour of which is both prejudicial to the breath and injurious to many sorts of apparatus. In platinum batteries this evil may, in some degree, be remedied by means of a lid, made to fit the earthenware cell. In the carbon batteries it is less easy to apply this remedy. Warrington and Dr. Leeson substituted for the sulphuric acid a liquid composed of 3 parts of bichromate of potassa, 4 of concentrated sulphuric acid, and 18 of water. Poggendorf says that he found the electromotive influence it excited in a carbon battery equal to that produced by sulphuric acid, but that its character was less steady and permanent; when used with platinum batteries, he says, it is far less effective than sulphuric acid.

§ 506.

The tension excited between the electromotors of any simple voltaic arrangement is, after all, very feeble. Its intensity may, however, be increased by connecting several of them together; a discovery which has immortalized Volta's name. A combination of this kind is termed a *compound hydro-electric battery*, or a *Voltaic pile* or *battery*; sometimes it is called a *galvanic battery*. In constructing it, the like metals in the individual batteries must all be ranged one way; as for instance, all the copper on the left hand and all the zinc on the right: and in this order the heterogeneous metals must be joined by a good conductor, or else they must be placed in immediate metallic contact.

The essential form of such a combination may be represented in the annexed diagram:

$$C\,l\,Z \frown C\,l\,Z \frown C\,l\,Z \frown C\,l\,Z,$$

C being the copper, Z the zinc, and l the intermediate liquid, $\frown$ represents the metallic connection or contact.

The individual members of these compound batteries may be variously arranged according to the nature of the single batteries of which they are composed. The following are the chief: —

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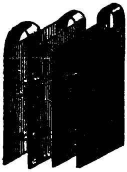
* NOTE. Mr. Walker in his Treatise on Electricity expresses his estimate of the comparative merits of Platinum and Carbon, in the following pithy manner.—"Platinum is in the long run decidedly preferable to Carbon; as *experience* will soon teach."

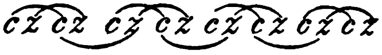
1.) *Single-fluid batteries.* — The oldest of all, invented in 1800, and still in frequent use, is named after its inventor, the *Voltaic pile.* It consists of round or square plates of copper and zinc, commonly from 1 to 4 inches across. The pile is formed by placing them one on the other, a zinc and a copper plate being soldered together throughout. Care is to be taken that all the copper plates are underneath, and all the zinc uppermost, or *vice versâ.* Between each pair of plates insert a piece of flannel or pasteboard, saturated with the liquid *l*, which is generally either dilute sulphuric acid, or a solution of common salt; and the elements of the galvanic circuit will stand in the following order, beginning from the bottom of the pile Z C *l* Z C *l* Z C *l*, &c. When from 30 to 50 pairs of plates have been thus arranged, the flannel soaked in the liquid will be subjected to such a pressure, that a great portion of the liquid will run down. If, therefore, the number of plates is considerable, say 100 or more, it would be better to make two piles of 50 pairs each, near together, but in inverse order, and connect either the undermost or the top plates by means of a strip of copper. In this arrangement, the outermost zinc and the outermost copper plate may be dispensed with, as they are not in contact with the liquid, and the last copper plate will have a positive electrical tension, and the last zinc plate a negative tension, just the same as in the single battery. — The electromotive power in such piles is increased by amalgamating the zinc plates; in which case the sulphuric acid may advantageously be diluted with from 20 to 30 times its amount of water. Muncke asserts that its power may be increased from two to four fold, by covering the pasteboard, which is to be soaked in the liquid on one side, with powdered black-lead, and laying that side next the copper. The electromotive power may also be increased by substituting some more negative metal, as silver for the copper; and according to Bunsen, the maximum effect is gained by making the pile of amalgamated zinc and copper plates, and using Warrington's chromic acid liquid, described a little higher up. Bunsen says, that from a cylinder of fine carbon (for its preparation, see the preceding section), 7 inches long, 100 slices may be cut, which will not require cleaning like the copper discs, as they need only to be kept in the liquid when not in use.

Compound batteries may in like manner be formed of Wollaston's trough apparatus, Oersted's trough or Hare's spiral batteries, merely observing to place the individual members of it in the same order, and then connecting them by means of copper wires. The whole is to be immersed in the liquid, either in a trough of sufficient size to contain it, or the liquid must be poured into the separate copper or glass cylinders.

Faraday's trough apparatus, improved by Young, will be found very convenient for readily constructing an efficient pile of many plates. The copper and amalgamated zinc plates, presenting a surface of about 4 square inches each, are to be ranged alternately in a wooden frame. Every two copper and zinc plates are connected by a strip of metal, as is shown in *fig.* 185. When several such pairs are combined in a battery they are put together, so that one copper plate stands between two connected zinc plates, and one zinc plate between two copper ones, the distance between each being one line. This combination is represented in the annexed diagram, C standing for the copper, Z for the zinc, and ⌒ for the metallic connection : —

Fig. 185.




C Z C Z C Z C Z C Z C Z C Z C Z

After the plates have been thus arranged, plunge them into a trough of convenient size, of either wood, earthenware, or japanned ware, containing either sulphuric acid diluted with from twenty to thirty times the quantity of water, or Faraday's liquid, the composition of which we have given above. When the operation of the battery is to be discontinued, you have only to lift out the plates by the common frame in which they all stand.

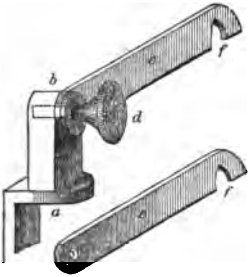
The following batteries of this class merit a brief notice on account both of their magnitude and their remarkable performances. The great battery of the Royal Institution in London consisted of 2000 pairs of plates, each of which had an effective surface of twenty-two square inches; it was with this apparatus that Sir H. Davy made the important discovery of the compound nature of alkalis, and the practicability of their being decomposed. Next to this we may mention Children's great plate battery, which consisted of 16 pairs of plates, combined on Wollaston's principle, each plate being 6 feet long by 2⅔ feet wide, so that the effective copper surface of each was 32 square feet, and when these were connected in *one* the entire surface amounted to 512 square feet. Hare's deflagrator or calorimotor was combined of 80 zinc and copper spirals, the zinc surface containing 54 square inches, and the copper 80 square inches. Stratingh's deflagrator consisted of 100 pairs arranged on Wollaston's principle, each zinc surface presenting 200 square inches; it could be used either as a pile of 100 pieces, or as a single battery of 40,000 square inches of zinc (or 277 square feet of zinc, and 544 of copper).

All these single-fluid batteries have, however, fallen into disuse, except when powerful physiological effects (§ 515.) are to be produced, since the discovery of the great efficacy of batteries with two liquids, which with a smaller number of pieces varying from 2 to 40, of average dimensions, (having an effective surface of from 20 to 100 square inches,) exert a power equal to that of the gigantic battery belonging to the Royal Institution.

These batteries are made by combining either Daniell's, Grove's, or Bunsen's single batteries, arranging the individual members of the compound battery near to one another, and connecting the heterogeneous electromotors on the principle of a voltaic pile by strips or wires of copper. It is convenient to divide the number of component members into two equal factors, that they may be easily arranged in a rectangular space. The Grove's battery, constructed by Jacobi of Petersburg, contains 64 platinum plates, each of 36 square inches surface, so that their combined surface amounts to 16 square feet. Probably this is the most powerful battery ever made. not excepting even that of the Royal Institution; for, according to Jacobi's comparative estimate (see the preceding paragraph), its effect is equal to a Daniell's battery of 266 square feet, or a Hare's battery of nearly 5500 square feet.

It is of essential importance in all compound batteries, not to waste the electromotive power, and to ensure their utmost efficiency, that a perfect metallic contact should be established between the parts by means of short and good conductors. Copper wire, or strips of copper of suitable thickness, are the best conductors; if they are not immediately fastened to the heterogeneous metals, as in Wollaston's and Young's batteries, small cups may be soldered on to the metal plates, these cups filled with mercury, and the ends of the connecting wires immersed in this liquid metal. Or the many inconveniences attending the use of quicksilver may be obviated by the use of copper binding screws. In this case care must be taken that the contact of the metals is perfect. This will be best secured by electro-gilding (§ 519.) the points of the contact, which may be done at a small expense and with little trouble. A screw

Fig. 186.



and clamp of the kind referred to are represented in *fig.* 186. *a* is a strip of metal bent at right angles, and soldered on to each of the electromotors; on it stands an upright piece of metal *b*, turning on an axis or screw. In this upright a hole is drilled to receive the nut *d*, by which the strip of metal *c* is secured to *b*. A notch is made at *f*, in this last-named little bar, by which it may be fastened to the next piece of the battery by its connecting screw. All these pieces of apparatus should be of copper or brass; and for reasons already given, it is advisable to gild, silver, or platinize them by the volta-typing process.

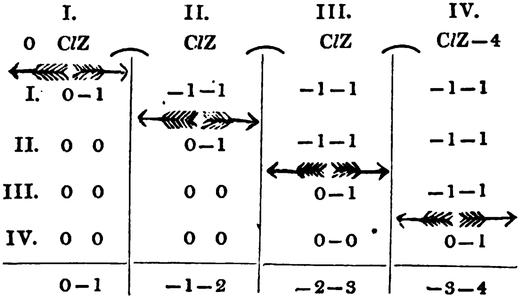
§ 507.

In any one of the batteries we have just been describing there arises a peculiar induction of the tension, excited by the contact of the electromotors with the intermediate fluid. The + and − electricities, elicited in the respective metals, are urged in opposite directions to the sides on which the similar electromotors are ranged, the connecting wires and the intermediate liquids acting as conductors. The dissimilar electricities are accordingly accumulated in the two extreme electromotors of the circuit, which are hence called *poles*; that being termed the *positive pole* towards which the + electricity tends, and the other the *negative pole* towards which the − electricity moves.

As in the arrangement of a common voltaic battery (see the preceding paragraph), its poles consist of a pair of zinc and copper plates, and as the outermost plate of the + pole is zinc, and that of the − pole is copper, the + pole has sometimes been called the *zinc pole*, and the − the *copper pole*.

If, according to the construction described in the preceding paragraphs, the last member of the circuit, the copper for instance, be connected with the earth, its state of positive electrical tension will disappear, and it will acquire 0 electricity. The electrical tension of the other electromotor of the voltaic pile communicates the like tension by means of the conducting wire to all the other members of the circuit. The like happens to the second, third, fourth, &c. members of the whole battery; whence, consequently, the electricity is carried off from all the electromotors of the same name (in the case supposed from the copper plates), which lie on the side that is in contact with the ground. The electricity of the other electromotors, *i. e.* of the zinc plates, will be the sum of that of the successive pieces; thus the intensity of the —electricity towards the opposite pole increases in arithmetical progression, so that in the *n*th plate of the battery, the tension would be *n* times greater than in the first. The same ratio obtains with regard to the + electricity, if the outermost zinc plate be connected with the ground. Biot, who has performed a number of exact experiments to ascertain this point, found the electrical tension in such batteries was altogether independent of the magnitude of the effective areas of the electromotors; so that, if the electromotive combination of two batteries be alike, and they consist of the same number of plates, the intensities of their tensions will be equal, even though the electromotors of one battery be 100 times larger than those of the other.

The annexed diagram will perhaps render more easily intelligible the increasing tension and induction of the electricity in compound batteries. C expresses the copper which is in a state of positive, and Z the zinc, which is in a state of negative tension; *l* is the exciting liquid for the two metals; ⌒ the connecting wire between them; and the ⋙→ marks the direction taken by the + and — electricities in the circuit; the intensity of the tension in each single battery is assumed = 1, and the extreme copper plate is supposed to be connected with the ground.



	I.	II.	III.	IV.
0	C*l*Z	C*l*Z	C*l*Z	C*l*Z — 4
I.	0 — 1	— 1 — 1	— 1 — 1	— 1 — 1
II.	0 0	0 — 1	— 1 — 1	— 1 — 1
III.	0 0	0 0	0 — 1	— 1 — 1
IV.	0 0	0 0	0 — 0	0 — 1
	0 — 1	— 1 — 2	— 2 — 3	— 3 — 4

If the zinc plate be connected with the ground instead of the copper one, we shall have a similar scheme, with this difference only, that the tension increasing through the successive members of the battery will be positive: the scheme can of course be carried to any number of terms at pleasure.

Next, we will suppose both the ends or poles of the battery to be insulated; we will further assume its electromotors to be copper and zinc, that the former is on the right and the latter on the left hand; then it follows that the + electricity of the copper runs through all the plates in the circuit to the left hand, and the − electricity of the zinc to the right. Hence there proceeds from the middle a progressive accumulation of + electricity towards the left hand, and a similar accumulation of − electricity towards the right; so that the two extreme plates exhibit an increased intensity of tension, whilst in the centre it ceases altogether, the centre being, in fact, its point of indifference. Remove the connecting wire from any two members of the series, and you obtain two batteries, in which the same electromotive condition is found to exist as has been just described: disconnect a second wire and the like occurs again.

The following diagram will perhaps render the above more easy to comprehend; the same signification is to be attached to the symbols as in the former scheme. Assume the tension between the copper and the zinc $=1$, then, if each is perfectly insulated, the difference of their tensions will remain the same, that of the copper being $+\frac{1}{2}$, and that of the zinc $-\frac{1}{2}$.

Diagram of a Battery of Three Pairs of Plates.

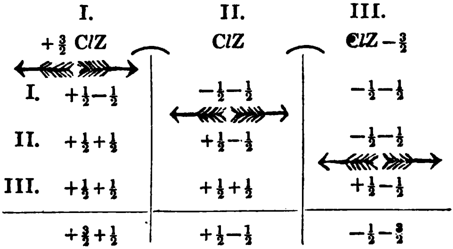
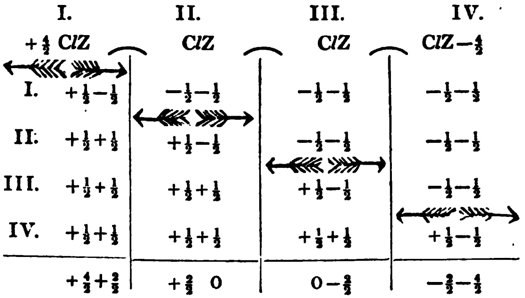
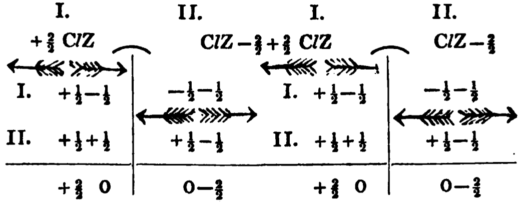

I.
II.
III.
$+\frac{3}{2}$ ClZ
ClZ
ClZ $-\frac{3}{2}$
I. $+\frac{1}{2}-\frac{1}{2}$
$-\frac{1}{2}-\frac{1}{2}$
$-\frac{1}{2}-\frac{1}{2}$
II. $+\frac{1}{2}+\frac{1}{2}$
$+\frac{1}{2}-\frac{1}{2}$
$-\frac{1}{2}-\frac{1}{2}$
III. $+\frac{1}{2}+\frac{1}{2}$
$+\frac{1}{2}+\frac{1}{2}$
$+\frac{1}{2}-\frac{1}{2}$
$+\frac{3}{2}+\frac{1}{2}$
$+\frac{1}{2}-\frac{1}{2}$
$-\frac{1}{2}-\frac{3}{2}$

Diagram of a Battery of Four Pairs of Plates.


I.
II.
III.
IV.
$+\frac{4}{2}$ ClZ
ClZ
ClZ
ClZ$-\frac{4}{2}$
I. $+\frac{1}{2}-\frac{1}{2}$
$-\frac{1}{2}-\frac{1}{2}$
$-\frac{1}{2}-\frac{1}{2}$
$-\frac{1}{2}-\frac{1}{2}$
II. $+\frac{1}{2}+\frac{1}{2}$
$+\frac{1}{2}-\frac{1}{2}$
$-\frac{1}{2}-\frac{1}{2}$
$-\frac{1}{2}-\frac{1}{2}$
III. $+\frac{1}{2}+\frac{1}{2}$
$+\frac{1}{2}+\frac{1}{2}$
$+\frac{1}{2}-\frac{1}{2}$
$-\frac{1}{2}-\frac{1}{2}$
IV. $+\frac{1}{2}+\frac{1}{2}$
$+\frac{1}{2}+\frac{1}{2}$
$+\frac{1}{2}+\frac{1}{2}$
$+\frac{1}{2}-\frac{1}{2}$
$+\frac{4}{2}+\frac{2}{2}$
$+\frac{2}{2}$ 0
0$-\frac{2}{2}$
$-\frac{2}{2}-\frac{4}{2}$

Subdivision of a Battery of Four Pairs of Plates into Two of Two Pairs each.


I.
II.
I.
II.
$+\frac{2}{2}$ ClZ
ClZ$-\frac{2}{2}+\frac{2}{2}$ ClZ
ClZ$-\frac{2}{2}$
I. $+\frac{1}{2}-\frac{1}{2}$
$-\frac{1}{2}-\frac{1}{2}$
I. $+\frac{1}{2}-\frac{1}{2}$
$-\frac{1}{2}-\frac{1}{2}$
II. $+\frac{1}{2}+\frac{1}{2}$
$+\frac{1}{2}-\frac{1}{2}$
II. $+\frac{1}{2}+\frac{1}{2}$
$+\frac{1}{2}-\frac{1}{2}$
$+\frac{2}{2}$ 0
0$-\frac{2}{2}$
$+\frac{2}{2}$ 0
0$-\frac{2}{2}$

Electroscopic observations will at once prove the existence of these particular states of tension in the different batteries; if, however, the electroscopes or electrometers used are not sufficiently delicate to indicate the tension, we must call in the aid of a condenser, by means of which the feeblest degree of tension will be rendered visible.

Compare a pile both whose poles are insulated with another, one of whose poles is connected with the ground, and the following differences will be observable:—That which is not insulated shows throughout its whole extent only + or only — electricity, the other has 0 electricity at the pole in connection with the ground, from which to the other pole the intensity of the tension continually increases. In the battery whose poles are insulated, both species of electricity are found proceeding from the centre or point of indifference, so that one half contains only + and the other only — electricity, increasing equally in intensity towards each pole; however, the intensity at each pole of that battery, which was insulated at both ends, is only half that of the insulated pole of the second battery, which had its other pole connected with the earth.

The insulated piles in this respect present a striking analogy to the polarity of a bar magnet, in one half of which in like manner +electricity resides, and −electricity in the other half; in the middle, between the two poles, is the point of magnetic quiescence, or 0 electricity; and if the bar be divided, each of the fragments acquires a similar polarity. (§ 436.)

§ 508.

Besides the electrical piles already described there are some others in which the elements composing the individual members of the battery are somewhat differently combined, viz. the *dry piles*, *piles of two elements only*, and *secondary piles.*

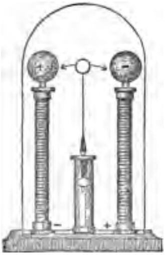
The first, called also after their inventor, *Zamboni's piles*, differ from the common hydro-electric batteries principally in this, that the presence of the electromotive liquid is dispensed with in them, and that in its place is substituted some moist substance of low conducting power, generally paper. The electromotors in these piles are composed for the most part of Dutch gold (copper) and silver (zinc) paper pressed one on the other, with their paper sides together, out of which discs are cut with a diameter of from ¼ of an inch to an inch. More powerful pairs of plates may be obtained by using only the silver paper and smearing its paper side with a thin coat of honey, on which some finely pulverized peroxide of manganese has been sprinkled, and all the sides similarly coated are presented one way. Powerful pairs of plates may also be made by pasting pure gold leaf on the paper side of zinc-paper. These plates are then to be arranged, just as in the ordinary voltaic pile, one above the other, so that the similar metallic surfaces may all lie one way; press them tightly together; tie them with pretty stout silk threads, and press them into a glass tube of convenient size. The metal rims of the tubes, which must be well connected with the outermost pairs of plates, form the poles of the pile, the negative pole being in the extreme zinc surface, and the positive in the extreme copper or manganese surface.

The electromotive energy called into action in these dry piles is less than that excited in the moist or hydro-electric piles, principally on account of the imperfect conduction of the paper. The accumulation of electricity at their poles also goes on less rapidly, and consequently the electrical tension continues for a long while unaltered; whereas, in all moist piles, even in the most constant of them, the tension is maintained, comparatively speaking, for but a short time, on account of the chemical action and decomposition of the electromotive fluid — causes of disturbance which do not exist in the dry pile. To render the electrical tension of a Zamboni's pile immediately perceptible on an electrometer without condensation, the pile must consist of at least from 600 to 1000 pairs of plates.

Behrens, Deluc, Biot, Jäger, Ritter, Kämtz, and others have at different times employed various materials in the construction of similar dry piles, but none have been found to be equal in power to those made of zinc-paper and manganese. Watkins, of London, made a remarkable pile of only one metal, and without any intermediate conductor. It consisted of from 60 to 80 zinc plates, about 4 square inches in size, purely metallic on one side, but on the other covered with the ordinary film of oxide. These plates were so arranged in a wooden trough, that all the clean metallic surfaces stood one way, and between each pair of plates there was an extremely fine stratum of air, as they were not in immediate contact. In this apparatus the two zinc surfaces acted as the two different metals do in other piles, and the film of damp air performed the part of the paper.

The length of time during which the tension of these piles lasted led to the construction of a kind of *electrical perpetual motion*. It is formed by placing two Zamboni's piles (*fig.* 187.), each containing at least 1000 pairs of plates, in a vertical position within 1½ inch or 2 inches of each other, so that their dissimilar poles may be opposite both at top and bottom. The lower poles are then connected by means of a strip of copper, but the upper terminate in two metal knobs. Now, between these two polar balls, place a light pendulum, just balanced above its centre of gravity. The pendulum rod should be of glass or gum-lac, and on its top it may carry a small ring or ball of gold or silver, which on coming in contact with one of the poles of the battery is impregnated with its electricity. It is then repelled, both being similarly electrified. The other pole attracts it, electrifies it, and then repels it, and thus this oscillating movement is maintained without cessation. As the action of these piles is, after a time, impaired by external causes, the expectation has not been realized, that they would supply a perpetual motion.

Fig. 187.



Bohnenberger's electroscope, improved as it has since been by Becquerel and Fechner, is an apparatus of far greater utility than that we have just described. It acts on the principle of the permanent tension in a Zamboni's pile. We have already (§ 480.)

described this extremely delicate instrument (*fig.* 157.), and have pointed out its application. The action of the small dry pile on the electroscopic gold leaves, vibrating between its two poles, will be perfectly understood from what has just been advanced.

The piles of two elements only, likewise an invention of Zamboni, consist of one metal and one intermediate conductor, either dry or moist; if the former, the discs are of silver paper, laid with all their metal sides one way; if the latter, a number of pieces of tinfoil of some such shape as this ◊, are laid in two watch-glasses which contain water, in such a manner that the pointed half lies in one glass, and the broad end in the other. After some time these piles acquire at their poles a feeble electrical tension, which they will maintain for several days, the metal pole exhibiting + electricity in the dry pile, and the pointed end of the zinc being + electrified in the moist one.

The *secondary piles*, sometimes also called *Ritter's* piles, consist of alternate layers of homogeneous metal plates, between which some moist conducting substance is interposed. When they stand alone no electromotive tension is excited; but after they have been for some time connected with the poles of a voltaic battery, if they be disconnected from it, the end which was joined to the positive pole of the battery will have become + electrified, and that which was connected with the negative pole will be − electrified. A similar effect may be produced in silver, gold, and platinum wires, if of sufficient thickness, by connecting their ends alternately, the one with the + and the other with the − pole of a powerful battery, and maintaining this connection for about an hour. The charge is only transient in its duration, and passes off the more quickly the fuller the tension in the first instance. Various attempts have been made to explain this phenomenon, which seems most probably connected with some polarizing influence.

C. *Voltaic Piles in an Electro-statical and Electro-dynamical Condition.*

§ 509.

Both simple and compound voltaic batteries, in the condition which we have considered as yet, display their electromotive activity solely by the *electropolar tension* of their elements, the electromotors being excited by contact with the intermediate liquid, or with some dry conductor. The intensity of this tension, compared with that produced by friction, even in batteries consisting of a great number of plates, is extremely weak, as electroscopic observations prove.

This is sometimes called the *electrostatic* condition, which may be converted into the *electrodynamic* by connecting the two electromotors of a single, or the two poles of a compound, battery together, by means of any good conductor. The ± electricities rendered sensible are set in motion, and a current is generated the same as in frictional electricity, in which the ± electricities combining produce 0 electricity. The connections may be variously formed, the main point being that they be of good conducting materials (§ 469.), however shaped or combined, as substances of low conducting power would not transmit the current. The connection is established in the most simple manner possible, by placing those parts of the electromotors which are not immersed in the liquid together, or else they may be joined by a wire or strip of metal. Other conducting bodies may form parts of the circuit, as *ex. gr.*, a fluid, a living animal, or vegetable, &c. Outside the simple voltaic arrangement, the current goes from the negative metal, as being the electromotor which is in a state of positive tension. Outside the compound battery it runs from the + pole through the connecting arc to the negatively excited electromotor; that is to say, to the positive metal, or to the − pole, whereas, within the battery itself the current runs in exactly the opposite direction; that is to say, in a single voltaic arrangement from the positive metal through the electromotive fluid to the negative metal, and in a battery from the negative pole through all the intervening pairs to the positive pole. In the single batteries represented in *figs.* 175—177, the direction of the current is marked by arrows. In this case, by the current, is to be understood only the positive one; the negative current arises simultaneously with it, and runs in an opposite direction. (§ 488.)

§ 510.

Faraday has adduced a variety of proofs to establish the identity between electricity excited by contact and by friction; the important distinction between them is, that in the former, the exciting cause is constant, and by consequence the effect is so too, but in friction electricity this is not the case. The conductor of an electrical machine when charged, as we have already seen, loses its electrical tension immediately on a connection being established by a good conductor between it and the ground, and we can only obtain an approximation to a constant stream in a good conductor by connecting it, while the machine is in action, with the prime conductor and cushion. An electrical battery shows the same defect, for, when it is discharged, the current sent through the conductor is instantaneous, and to renew the effect the battery must be recharged. In a voltaic battery, on the contrary, the exciting cause is permanently at work; hence, after connection is established with the ground, its electrical tension is excited and maintained, and when the circuit is completed, the stream is emitted uninterruptedly so long as the circuit is not broken, and so long as no change takes place in the electromotive powers of the electromotors and their intermediate liquid; because, so long as the ± electricities in the interior of the battery neutralize each other by the current, the condition is re-established on which a new electromotive excitation depends. Again, there is a difference in the effects of voltaic and friction electricity, owing to the quantity and intensity of the electricity developed by each of these modes respectively. By friction, a current is obtained of great intensity, but containing a small quantity of the electric fluid; by voltaism, generally speaking, a much larger quantity is developed, but always of a low degree of tension: hence the largest electrical battery may be charged, by means of a voltaic pile, instantly to the degree of tension shown by the latter at its poles, by connecting the two together by means of wires. A still more decisive proof of the difference as to the quantities of electricity obtained from these two sources is afforded by an experiment of Faraday's, which will be explained below. (§ 512.) In consequence of this difference, all those operations which depend principally on the intensity of the electric fluid are more feeble in the voltaic than in the ordinary electric current, while such as are dependent on its quantity and duration are stronger than those of the latter. The above remarks must be understood to refer exclusively to hydro-electric batteries, as the current emitted by the dry piles is extremely feeble.

§ 511.

It now remains that we should describe and explain the different effects exerted by a hydro-electric current in its passage through different bodies. To do this properly, and to judge correctly of its influence, we must first learn on what the absolute force of a current particularly depends, and by what causes this force may be modified. Accurate conclusions as to these matters have only been arrived at within comparatively a few years, to which conclusions we have been conducted in part by the shrewd theoretical deductions of Ohm, and the careful observations of Fechner and others.

In all investigations of this kind, it is requisite that we should have an accurate measure of the intensity of the current, in order to learn the influence exerted on it by the varied combinations of the batteries, and the changes which arise in its intensity. The different effects which the current produces furnish us with such a measure; they are not, however, all equally well adapted for this purpose; we shall presently (§ 522.) show which are to be preferred, and how they are to be applied.

There are two factors which especially determine the absolute intensity of the current, and on whose variations the intensity of the effects produced regularly depends. One of these, which is also the proximate or exciting cause of the electric current, is the *electromotive force* itself; and the other, or modifying cause, is the *resistance to its conduction.*

The electromotive force depends on the *quantity* or *mass* of electricity set in motion. In simple voltaic arrangements the quantity of electricity expresses the difference of the tension between the two electromotors; it depends both on the manner in which they are combined (§ 505.), and also on the extent of their surfaces in contact with the intermediate fluid. In a compound battery the whole force will be proportional to the sum of the electromotive forces of the individual pairs composing it.

The *retarding force* is compounded of the different obstacles which impede the progress of the current; it forms the factor by which its effect is more or less impaired. These obstacles arise in part from the *imperfect conducting power* of the bodies completing the circuit, and in part from the *resistance* which the current encounters every time it passes from one conductor to another.

The *conducting power* of a body, or its capacity for transmitting electricity, varies with its material structure: that of the metals is some millions of times superior to that of the best conducting liquids, with which they have been compared.

The conducting powers of the metals, ascertained in various ways, are as follow:—According to

Becquerel.		Ohm.		Davy.	
Copper	= 100	Copper	= 100	Silver	= 109·1
Gold	= 93·6	Gold	= 57·4	Copper	= 100
Silver	= 73·6	Silver	= 35·6	Gold	= 72·7
Zinc	= 28·5	Zinc	= 33·3	Lead	= 69·1
Platinum	= 16·4	Brass	= 28·0	Platinum	= 18·2
Iron	= 15·8	Iron	= 17·4	Palladium	= 16·4
Tin	= 15·5	Platinum	= 17·1	Iron	= 14·6
Lead	= 8·3	Tin	= 16·8		
Mercury	= 3·45	Lead	= 9·7		
Potassium	= 1·33				

Lenz. At 32° Fahr.		Reiss.		Pouillet.	
Silver	= 136·25	Silver	= 148·74	Gold	= 103·5
Copper	= 100	Copper	= 100	Copper	= 100
Gold	= 79·79	Gold	= 88·87	Platinum	= 22·5
Tin	= 30·84	Cadmium	= 38·35	Brass	= 15·2 = 23·4
Brass	= 29·33	Brass	= 27·70	Cast steel	= 13·0 = 20·8
Iron	= 17·74	Palladium	= 18·18	Iron	= 15·6 = 18·2
Lead	= 14·62	Iron	= 17·66	Mercury	= 2·6
Platinum	= 14·16	Platinum	= 15·52		
		Tin	= 14·70		
		Nickel	= 13·15		
		Lead	= 10·32		

The above numbers express the relative lengths of the wires which, with equal diameters, conduct the same quantity of electricity.

The conducting power is not always uniform, it varies according to the temperature and the force of the current: Lenz's experiments on this subject prove that the conducting power of metals decreases when their temperature is raised, that the rate of this decrease varies in different metals, and that in all it is confined within certain limits: with regard to liquids, Mariani has shown that their conducting power is increased by raising their temperature. The current of electricity itself, as we shall see presently, is the principal cause of the conducting bodies' increase of temperature; it acts variously, according to the nature of the liquids employed, chemically decomposing them as it passes through them, and thereby, in a short time, frequently impairing their conducting power to a great extent.

It is self-evident, that the better conducting power any substance possesses, the less will be the resistance to be overcome by the current in its transmission through such a body. The amount of this resistance depends not merely on the structure of the conductor, but also on its length, thickness, and temperature. Hence, that portion of the resistance in each body really owing to its material structure, can be ascertained only by giving equal lengths, breadths, and temperatures to the bodies compared together. Fechner, from experiments which he performed, with the accuracy and ingenuity for which he is distinguished, discovered the following laws:

The resistance offered by the metallic portions of the pile or battery, is directly as their lengths, inversely as their transverse sections, (in wires, as their diameters squared,) and inversely also as their conducting power, which is, however, influenced by their temperature. By length, is to be understood their dimensions in the direction in which the current travels.

The resistance of the liquid conductor is proportional to the distance of the electromotors from each other in the liquid, inversely as the extent of the metallic surface acted on by the liquid, inversely also as the conducting power of the latter, which, however, is affected by the temperature.

Let l be the length of the metallic conductor, or the thickness of the stratum of liquid between the electromotors; t the transverse section, or area of the surface acted on; c the conducting power; and R the resistance, which may be expressed by the following formula:

$$R = \frac{l}{t. c}$$

Besides the resistance to conduction of the metallic and liquid parts of the battery, the current has further to overcome the *resistance to transmission* each time it passes out of a liquid into a solid body, whether it be an electromotor or merely a conductor of electricity, and *vice versâ*. In this we have a striking analogy to the vibrations of sound, light, and heat, which are always retarded by passing out of one medium into another; and if the idea be correct, which some have entertained, that electrical phenomena are caused by certain undulations in the æther, this resistance offered to the current might be explained in the same manner as the retarded undulations spoken of above. Fechner first noticed this resistance, the existence of which, and the causes by which it was affected, he proved by a variety of experiments. Poggendorf also performed numerous experiments, by which he was led to the following conclusions.

The resistance to be overcome by the current in its passage from the solid to the liquid, and *vice versâ*, depends on the conduction of the electric fluid in the interior of the bodies; it varies, consequently, according to the nature of the liquid and that of the metal in contact with it, being very much influenced by the character of the surface of the latter. The less powerful the electric current the stronger the resistance at the points where it quits one conductor for the other. If the surface to be traversed be changed, but the intensity of the current remain the same, then the resistance varies in a ratio rather less than the inverse ratio of the increase in the surface. If the temperature be raised it is diminished, and in the passage of the current from one metal to another it is indefinitely small.

To estimate the resistance to conduction in a battery, we must be acquainted with the resistance of some one commensurable body, such as a wire of known material, length, thickness, and temperature; the resistance such a wire actually offers, or which it would offer if it formed a part of the battery, will serve as our unit of measurement. This resistance is estimated according to the results effected by the action of the current, and it will serve as a unit for comparing similar actions. Hence the resistance to the conduction of the current offered either by any other body, or by any particular part of the battery, may be expressed by some multiple, or some fraction of this unit; or, what is the same thing, we may find what equivalent length of wire will make the same resistance. Ohm called the resistance referred to such a unit *the reduced length*, and a body or a part of a battery of *n* times the reduced length is equal to another whose resistance to conduction is *n* times that of the wire, which is considered as the unit.

> If now we have a number of wires of various metals, and of the same thickness as the normal wire, their lengths must be respectively as their conducting powers, in order that their resistance to the transmission of the electric current may be the same as that of the normal wire; if this proportion be observed, we may substitute one of these wires for another to connect the battery, and in each case the resistance will be equal; if the wires be of the same metal, but of unequal thickness, this resistance diminishes as the squares of their diameters. Suppose, now, the unit of measurement is a copper wire 10 inches in length, then adopting the values given by Riess, an equal resistance would be offered by an iron wire of the same thickness and $1\frac{3}{4}$ inches in length, or by a platinum wire $1\frac{1}{2}$ inches long, or by a leaden wire $1\frac{3}{100}$ inches, or by a silver wire 15 inches long: each of these wires may be n^2 times longer, if it be *n* times thicker, without its resistance to conduction being increased. In like manner we may determine the magnitude of the retarding force of any other conductor whatever, by means of which we establish the connection of the battery. Suppose, now, we wished to know what must be the length of a copper wire that would offer a resistance to the conduction of the electric current equal to that of the human body, we must first find what length of wire would equal the reduced length of the human body. In order to determine the ratio between the resistance of any single member of the pile to the human body, we have only to substitute the one for the other, and thence determine the equivalent length of wire, which, multiplied by the number of pairs of plates in the battery, will give the reduced length of the whole battery, and it will always be found that its resistance to conduction is much less than that of the human body.

Since, therefore, the conducting power of a body is intimately connected with the resistance a current of electricity has to overcome, the force of the current must always exceed this retarding influence, or motion will not ensue; hence it is apparent why certain substances may act as conductors to a powerful current which are non-conductors to a feeble current, their conducting power becoming an indefinitely small magnitude when the current is weak.

Now, with regard to the entire resistance which impedes the action of a battery, it is made up of two parts, viz. out of that resistance which the current meets with in its passage through the battery and that which is offered to it in the connecting wires exterior to the battery itself. The retarding force in the battery is equal to the sum of the retarding forces of the different pairs of which it is composed; it results, therefore, from the resistance to conduction offered by the stratum of fluid between the electromotors, from the resistance to the transmission of the current from the solid to the liquid and from the liquid to the solid, and from the retarding influence of the metal connecting contiguous plates. Hence it follows that in a similar combination of compound batteries the resistance will be proportioned to the number of plates. The retarding force of the connecting wires necessarily depends on the material of which they are made and on the mode of their combination; as a general rule, it is increased in proportion to the length and thinness of the wires and the lowness of their conducting power. It is especially aggravated by the interposition of bad conductors in the circuit, such as liquids or the human body, as by this means there is the further impediment caused by the current's passing out of one medium into another. This is, for the most part, that portion of the electric circuit on which the action of the whole battery is brought to bear in the performance of experiments; any change in it must necessarily affect the total resistance of the battery.

If now our object be to determine the influence of an electric current on the electromotive force, which is especially the active factor in exciting and maintaining the current, we shall find the following law of Ohm's important, as being applicable under all circumstances, and as referring to all the causes which tend to impede the action of the battery; it is, that *the intensity of an electric current, when a battery is in action, is directly as the whole electromotive force in operation, and inversely as the sum of all the impediments to conduction.* It may therefore be expressed by a fraction whose numerator is the electromotive force, and its denominator the sum of the resistance of all its parts. Let I be the intensity of the current, E the whole effective electromotive force in the battery, R its constant retarding influence, and r the variable retarding influence in the connecting wires; then

$$I = \frac{E}{R + r}.$$

By means of Ohm's fundamental law, which admits in its applications of the most varied developments, the first clear insight has been afforded into the apparently intricate circumstances which affect the performances of electrical batteries.

If, according to Ohm's formula, we put the intensity of the current in a simple voltaic arrangement whose excited surface is 1,

$$\text{I.}\quad I = \frac{E}{R + r};$$

then the intensity of a current from a battery of n pairs of plates will be

$$\text{II.}\quad I' = \frac{n\,E}{n\,R + r};$$

and in a single voltaic arrangement whose surface is n times greater than 1, the resistance to conduction being diminished inversely as the area of its transverse section, the intensity becomes

$$\text{III.}\quad I'' = \frac{E}{\frac{R}{n} + r} = \frac{n\,E}{R + n\,r}.$$

Now, if the action increases or diminishes in any part of the battery, either by an increase in the electromotive force (E), or by a decrease at any point in the retarding influences ($R + r$), the action of the battery will undergo a corresponding increase or decrease throughout, *i. e.* the increase or decrease of the intensity caused by a variation in the electromotive or retarding influences, is equally distributed throughout the battery. As, further, the effect of the current depends on the quantity of electricity circulating in the current, the amount of electricity flowing through every section of the battery will be equal, whatever its area or the material of which it consists. Wherever the space is narrowed through which the current flows, the mass of electricity must be more condensed, whereas in a larger section it becomes proportionally rare; in both cases the quantity transmitted is equal. The area of the section through which it passes will therefore regulate the *intensity* of the current, *which in every part of the electric circuit will be inversely as the transverse section of the conductor through which it passes*, *i. e.* it increases in proportion as the area through which it is transmitted is diminished. This variation in the *intensity* of the electricity whilst the *quantity* remains unaltered, is the cause of many of the phenomena of the voltaic current. The reader must not confound the *intensity of the current* in a battery at work with the *intensity of the polar tension* in an insulated battery; for the latter depends on the quantity of electricity liberated by its antagonist; it is measured by the repulsion of the particles of the dissimilar fluids, and is determined by its influence on an electrometer; whereas the intensity of a current of electricity depends on the quantity of the $\pm$ electricities which neutralize each other at every point of the circuit continually. The *total intensity* of the current will consequently be proportional to the quantity of electricity passing through every portion of the circuit, whilst its *relative intensity* will depend on the manner in which the quantity of fluid at each particular portion of the circuit exerts its influence.

From a consideration of the above, and especially from the explanation given of Ohm's law, as to the intensity of the current in a voltaic battery, we may draw the following inferences as to its action:—

1.) When the resistance to conduction offered by the connecting wires is very small, compared with that in the battery itself, the battery does not act with more power than each single pair of plates composing it; but a single voltaic arrangement acts the more powerfully the greater the excited surfaces of its electromotors.

> If the resistance to conduction, r, in the connecting wires, be very small, compared with that, R, in the whole battery, it may be disregarded, and the values of the intensities, I, I′, I″, in the preceding formulæ, become
>
> $$I = \frac{E}{R};\ I' = \frac{nE}{nR};\ I'' = \frac{nE}{R},$$
>
> or they are as
>
> $$I : I' : I'' = E : E : nE.$$

2.) Now in the converse case, that is, when the resistance to conduction in the connecting wire or other body is very great, as compared with that of the battery itself, then the action of the battery is more powerful, according to the number of pairs of plates composing it; but a larger pair does not act with perceptibly more force than a small one.

> In this case let R, the resistance of the whole battery to the conduction of the current, be indefinitely small as compared with r, that of the connecting arc; then, neglecting R in the preceding formulæ, we have for the intensities I, I′, I″ of the currents, the following values:—
>
> $$I = \frac{E}{r};\ I' = \frac{nE}{r};\ I'' = \frac{nE}{nr}$$
>
> or they are to each other as
>
> $$I : I' : I'' = E : nE : E.$$

3.) Since the resistance to be overcome by a compound hydro-electric battery, at any point of its circuit, affects its efficacy, we shall secure the maximum effect from a current in a battery of given surface, by making the resistance in the battery equal to that which the current has to surmount in the connecting wires.

4.) But since, in the construction of a battery, many causes are in operation by which the electromotive force may be influenced, such as the polarization of the metals (§ 504.), the chemical change produced in their surfaces, or in the intermediate liquids, it follows that a permanent and almost unvarying effect in the current can be attained only in those batteries where these disturbing causes exist in but a low degree, or where their forces paralyse each other. See § 518.

From the whole, then, it follows that the efficiency of all voltaic batteries depends entirely on quantitative differences, and that the same force, I, is to be maintained whatever change may be made in either term of the formula $I = \frac{E}{R + r}$, by which Ohm's law is expressed.

D. *Different Effects of the Hydro-electric Current.*

§ 512.

The effects produced by a hydro-electric current may be arranged under the following principal classes: 1.) *Magnetic*, 2.) *Luminous*, 3.) *Thermal*, 4.) *Physiological*, and 5.) *Chemical phenomena*, which we shall proceed to consider in the order in which they have been enumerated.

1.) *Magnetic Phenomena.* These are the last observed, not having been noticed until 1820. One of the most important of them we shall consider before speaking of any of the other effects produced by the electric current, because its discovery has furnished us with the readiest means of becoming acquainted with whatever is essential to be known concerning these currents. This phenomenon is the influence exerted by a stream of electricity on a magnetic needle, which, under its influence, acts both as an electroscope and an electrometer; hitherto we have considered these instruments merely as affected by electricity in a state of tension.

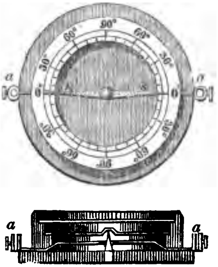
Every variation needle (§ 442.) placed near to a permanent electric current is deflected from its polar position, more or less, so that when the stream of electricity is transmitted from south to north below the needle, its north pole is turned eastward or towards the right hand, but when the current runs from north to south, the north pole of the needle deviates to the left hand or westward; these circumstances are exactly reversed when the fluid is made to go in the same directions above the needle. Currents of electricity sent simultaneously in opposite directions above and below a needle, deflect it still more powerfully. If the current be powerful, it is sufficient to carry it but once over or under a common needle in order to deflect it, but if the electric stream be weak, it must be conducted several times round the needle, thus repeating or multiplying the deflecting influence of the single current; if the current be extremely feeble, it may perhaps be requisite to use an astatic double needle (*fig.* 139.), in which the lower needle will stand between, while the upper one is above the currents, so that both directions of the stream tend to deflect the needle the same way. *Jacobi's Compass Galvanometer* (a) acts on the first principle, the *Multiplier* (b) invented simultaneously by *Schweigger* and *Poggendorf*, on the second, and *Nobili's Double Galvanometer* (c), on the third. The instruments just named are not equally applicable for all kinds of currents: the use of one or the other is regulated according to the end immediately proposed, whether it be to test the quality or the quantity of the current.

These instruments show the actual existence of an electric current by the deflection of their needles; from the direction they take we infer that in which the electricity was transmitted, and lastly, from the magnitude of the angle of deflection we learn the intensity of the stream of electricity, and the degree of resistance offered to its conduction by any part of the battery (d.) We shall presently show the relation subsisting between the deviation of the needle, and the intensity of the electric current (§ 522.), at the same time we will explain the various modes of estimating the intensity of such currents; for the present we must take it for granted that, in general, every current has a tendency to deflect the needle at right angles to its own line of direction, and that "cæteris paribus" those are the most powerful currents which cause the greatest deflection. We must refer the reader to the section on Electromagnetism for a full explanation of the theory on which the construction and use of these instruments rests; there also he will find an account of the various magnetic phenomena connected with them.

We shall at once proceed to describe the mechanical construction of such of these instruments as have come into most general use.

(a) *Jacobi's Compass Galvanometer, Fig.* 188., consists of

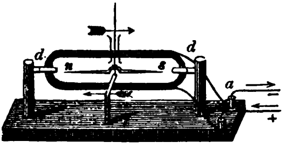
Fig. 188.



a common variation needle *n s* about 2 inches in length, under but close to which a copper wire about 1 line thick is carried, to the ends of which beyond the frame are fastened two mercury cups or binding screws *a*, by which this wire may be connected with the wires of the battery. The needle traverses the graduated circle: in using the instrument the needle should be set at O, that the current beneath may deflect it from *s* to *n* or vice versa.

(b) *Schweigger's Multiplier, Fig.* 189., consists of a fine

Fig. 189.



copper wire *d d* bent into an oval shape, in the middle of which a variation needle *n s* turns, being either supported on a point or suspended by a thread. The two extremities of the wire are attached to two mercurial cups or binding screws *a a*, by means of which the wire of the galvanometer is made part of the electric circuit. That the current may be compelled to traverse the whole length of the wire without springing from one turn of the wire to another, it is wound round with several coils of silk, and the whole is coated over with a varnish of gum-lac. The action of the multiplier is considerably affected by the number of circuits made by the wire, the number being regulated according to the purpose for which the instrument is intended, whether to measure powerful or weak currents; in the former case the wire is passed round but once, or at most but a few times, in the latter it is passed round more frequently. The common multipliers have the wire passed round from 100 to 300 or 400 times; for particular purposes the wire has been made to perform 1000 circuits; for instance, Fechner's multiplier had a copper wire of 16,454 feet in length, which was bent round 12,076 times. Its thickness also is of importance, and the feebler the current to be measured the finer should the copper wire be. Lastly, in using this instrument, as also the compass galvanometer, it will always be best to place the wire in the direction of the magnetic meridian; the angle of deflexion may be measured by means of a graduated circle placed beneath the needle.

(c) *Nobili's Double Galvanometer* differs from the preceding chiefly in the application made of a double astatic needle. One of the most modern construction is represented in *fig.* 190. The multiplying wire is passed over and under a cylindrical frame, *a a fig.* 190 a., so as to leave a small space between the circuits of the wire for the reception of the lower needle. The upper needle, *n s fig.* 190., turns just above the circuits of wire, on which a graduated card is laid like that represented in *fig.* 188. The double needle is suspended by a fine thread *f r* of unspun silk, fastened at *p* to a pulley, from which a common thread *r p* runs down the metal stand *r p t* to a screw *x*, by which it is moved, and thus the needle is raised or lowered at pleasure. To bring the coils of wire

Fig. 190 *a.*

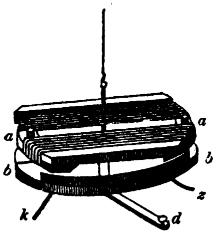
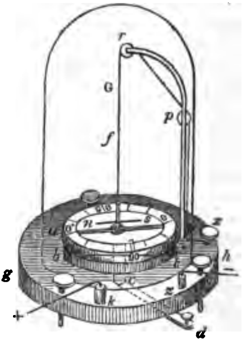


Fig. 190.



and the graduated circle into a proper position under the needle, the multiplier is fastened on a circular plate *b*, having in its centre a cylindrical plug which goes through a hole in the stand *g h* that supports the whole apparatus : to the end of the plug is attached a handle *c d* by which it is turned round. The two ends of the multiplying wire are connected with mercurial cups or binding screws *k z*, to which the conducting wires of the electric current are led. Three adjusting screws are placed beneath the stand to set the whole horizontally, and to secure the needle from draughts of air it is covered with a bell-glass G.

In these and all similar instruments the electric current must be sufficiently strong to overcome the directing influence of the earth's magnetism, or the needle will not be deflected. Hence it is evident that the sensibility of the apparatus, except that it may be increased by winding the wire a greater number of times, depends principally on the readiness with which the needle moves, and the smallness of its directing force. For these reasons it is better to suspend the needle by a thread than to rest it on a point, and we should use either single needles very feebly magnetized or an astatic needle. The following example will shew how greatly the power of the current circulating in the multiplying wire is increased in Nobili's multiplier. Suppose that the multiplier wire wound 333 times, then the original current would act on the lower needle with a force of 666, and on the upper with a force of 333 times what it would have possessed had the wire made but a single circuit; adding both together, with a force 999 or 1000 times as great. Both needles made, with a similar position of their poles, 57 vibrations in a minute, as astatic needles only 9. As the directing force of the earth's magnetism is proportional to the squares of these numbers (§ 449.), in the common needle this force will be 3248, and in the astatic needles 81, in the latter, therefore, it is 40 times less, and by consequence, the electric current acts with 40 times the force upon it. The deflecting power of the original current will therefore be increased by this galvanometer 1000 × 40 = 40,000 times.

(*d*) In a simple voltaic arrangement where the same connecting wire is used and the excited areas of the electromotors are equal, the deflexion of the needle will be greater, the greater the difference between the electrical tensions of the electromotors; this will evidently depend on the quantity of electricity set free by their contact and accumulated on their equal surfaces. Hence hydro-electric batteries of two heterogeneous metals and two different liquids (§ 505.) cause the greatest deflexion of the needle. In similar simple galvanic arrangements the deflexion increases with the increase of the electromotive surface acted on, but not quite in the same ratio, on account of the resistance to be overcome by the fluid in its passage from one element to another (§ 511.). In the same battery the deflexion of the needle decreases the greater the distance of the electromotors from each other in the intermediate liquid (§ 511.). In a compound battery, according to Ohm's law, when the resistance to conduction in the connecting wires of the multiplier is extremely small compared with that of the battery itself, the needle is not more powerfully deflected than by a single pair of plates (§ 511.).

Colladon was the first who proved that a stream of electricity, generated by friction, caused an analogous deflexion of the needle, thus furnishing additional evidence of the identity of frictional and contact electricity. To effect this we require a multiplier which makes a great number of circuits, and a continuous stream of the electric fluid; for this purpose the multiplier is interposed between a conductor running from the prime conductor of the machine to its cushion (a piece of wet tape will do very well); when the circuit is completed, set the machine in action; or charge a Leyden jar or battery by such a damp conductor, one end of it being connected with the outer, and the other with the inner coating of the battery. This last is the mode adopted by Faraday in his observations on electrical phenomena, in order to verify the contrast subsisting between frictional and voltaic electricity with regard to quantity. A very small voltaic battery consisting of one platinum and one zinc wire, $\frac{1}{18}$th of an inch thick, immersed in very slightly acidulated water, and held at a distance of $\frac{1}{3}$rd or $\frac{1}{2}$ an inch asunder for 3 seconds, deflected the needle of a galvanometer as much as the charge of an electrical battery of 8 jars which had been loaded with 30 turns of a powerful machine. When he used 15 jars and charged them with 30 turns of the machine, the quantity of electricity in the battery was the same, but its tension or density was rather less, and when discharged it caused precisely the same deflexion of the needle as in the first experiment; on turning the machine 60 times, the battery caused a deflexion of the needle twice as great as at first.

§ 513.

2.) *Luminous phenomena* occur at the moment when and at the points where the poles of a battery are connected by means of the connecting wires. The electrical spark is very small and short, for it is emitted when the wires are almost in contact with the poles of the battery; its colour and the intensity of its light depend on the metal by which it is rendered visible; probably this difference is owing to a partial combustion of the metal, at the points where the electric current passes from the poles to the wires When the connexion is established by means of mercury, the light is white and brilliant, if by means of iron or steel, it is of a reddish hue, with small scintillations radiating in all directions.

A spark of this kind will be emitted from a small hydro-electric arrangement of two plates only, but if the battery consist of several pairs of plates, the spark will be brighter; its intensity, however, depends rather on the extent of surface in contact with the fluid, than on the number of pairs of plates.

Very brilliant sparks may be obtained by means of a Grove's battery, of one zinc and one copper plate of ordinary dimensions, or with a few pairs of Bunsen's carbon battery; with either of these the following experiments may be performed.

Experiments. 1.) Bring nearly together the amalgamated ends of the polar wires, while the battery is in a state of activity, a small, white, starlike spark will be seen accompanied by a crackling noise like that which attends the emission of a feeble electrical spark.

2.) Plunge the end of one of the wires into a small vessel of mercury, and bring the other near the surface of the metal. A similar spark is emitted just before the point touches the mercury, on which a small black speck may be seen where the spark struck it.

3.) The spark obtained from an amalgamated point is visible under water or in the flame of a candle.

4.) Fasten a fine sewing-needle to the end of one of the wires, and touch the other pole with the free end of the needle; a starlike red spark will be emitted. A continued stream of these sparks may be obtained by connecting a small round or triangular file with one pole, and presenting to it and removing from it with great rapidity the point of a copper wire attached to the other pole.

5.) Coat the ends of the connecting wires with soot, by holding them in the flame of an oil lamp, and the sparks will be both larger and brighter; they will be obtained of the greatest intensity by holding the points of the wires in the flame opposite to each other.

Nobili says, that, in performing experiments of this kind he obtained the brightest sparks by connecting the two ends of the battery with a long spiral copper wire, or with a wire insulated by being wound round with silk.

§ 514.

3.) *Thermal phenomena.*— Heat is elicited when an electric current is generated by completing the circuit in a voltaic pile, it manifests itself in the connecting wires, in the electromotors, and also in the intermediate liquids. The intensity of the heat is regulated rather by the size than by the number of the plates; it is greatest in those batteries which have the greatest difference of tension (platinum and carbon batteries). This effect seems to depend more on the quantity of the electric fluid than on its intensity; the latter does, however, exert some influence, as Pfaff informs us, that with twice or three times the number of plates, a wire became hotter than when it was connected with a single pair; the heat is further dependent on the conducting power of the body, bad conductors of equal length and thickness with good ones becoming much hotter than the latter. Many attempts have been made to explain the causes by which these thermal phenomena are excited and modified. This has been done, on the whole, in the most satisfactory manner by Ohm, who assumes, that the degree of heat depends on the intensity of the electric current in the interior of a body, and also on its conducting power; according to Riess's experiments, it has been ascertained that the relative power of metals for acquiring electric heat, is directly as their retarding powers, or the resistance they offer to its conduction, and consequently, inversely as their capacity for heat and their density; these magnitudes may therefore be expressed by a fraction having for its numerator the retarding force, and for its denominator the capacity for heat and the specific gravity. These thermal phenomena seem further to be a result of the resistance which the conductors offer to the union of the $\pm$ electricities; whence, in addition to all other causes, its intensity will be greater, the greater the quantity of electricity neutralized in the electric circuit.

In the metal wires by which the poles of a battery in action are connected, the heat is manifested by the incandescence of the metal, or even by its combustion, the heat being the most intense in the finest wires.

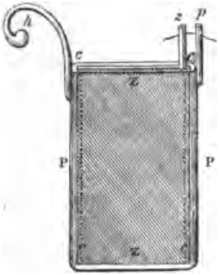
In very powerful batteries, such as Children's, Hare's and Strating's deflagrators, or even in platinum and carbon batteries, of considerable size, and from 10 to 20 pairs of plates, the development of heat is so great that substances, which are hard enough to resist the action of any furnace, are readily fused and burnt. To this may be added the remarkable fact, that these phenomena occur under circumstances in which we should not have expected them to happen, and under which they could not have been brought about by the ordinary process of combustion;

for instance, wires and charcoal points may be made red hot under water, and metals may be fused and burnt in vacuo, and in close vessels filled with gases which put a stop to the chemical process of combustion, such as nitrogen and carbonic acid gas.

The thermal influence of the hydro-electric current may be shown in the following experiments: —

Experiments. 1.) *Wollaston's thimble apparatus* is the smallest hydro-electrical apparatus ever constructed, by which the heating powers of the current have been made visible. This miniature battery is represented in *fig.* 191. of its actual size. P is a strip of thin silver or platinum leaf, bent so as to embrace an amalgamated zinc plate Z, at a distance of about a line. The insulation between the metals is effected by means of little pieces of cork thrust between them; *z* and *p* are the two copper or silver polar wires slit at the ends, into which is let a very fine platinum wire not more than a line in length. The wire hook *h* serves for suspending this little battery in a glass containing some dilute sulphuric acid (1 part acid to 4 of water). The current transmitted through the wire between *p* and *z* sets the latter in a state of incandescence.

Fig. 191.



Batteries of platinum and carbon are best adapted for producing powerful incandescence and combustion, especially on account of the steadiness of their currents. With one of these batteries of from 2 to 6 pairs of plates, each containing a surface of from 10 to 20 square inches of platinum or carbon, very brilliant effects may be produced. Nearly equal effects accompany the use of a battery of double the number of Hare's zinc and copper spirals, each of which should have a copper surface of from 150 to 300 square inches; it continues, however, in action but a short time, as after a quarter of an hour the intensity of the current is perceptibly lessened, whilst the other battery will maintain its action for an hour or more unimpaired. The following are the most important results which may be obtained from these batteries: —

2.) Connect the poles of the battery by means of a very fine iron or platinum wire, several inches in length, or a piece of thin watch-spring will do, and the metal will become red hot. Shorten the wire, and it will become white-hot and then melt; now use a stouter piece of wire, and the heat attained will be less. Substitute silver or copper wire of equal length and thickness with the iron or platinum wire that was raised to a red heat; in consequence of its better conducting power, it will merely be made hot without being melted; whereas a stouter and longer piece of either tin or lead would readily fuse.

3.) Establish a connexion between the poles by means of a stouter platinum wire pointed at the ends; fusion will take place at the points of contact, to which the wire will in a manner be soldered. The effect will take place even under water.

4.) Conduct the connecting wire through a small quantity of some saline solution, placed in a watch glass or an earthenware cup; the liquid will presently boil, and those parts of the wire beyond it will be made red-hot.

5.) Sulphuric æther, alcohol, phosphorus, gunpowder, and other combustible materials, may be ignited by making the connecting wire to pass through their mass, or to touch some part of their surface.

In consequence of their possessing this property, hydro-electric batteries have been used to spring mines, even under water, with success. Experiments on this mode of blasting were first made successfully by Hare, in N. America, in 1832, and by Morgan, who applied it to the blasting of rocks, and to other mining operations. Its applicability to the exploding of mines in war was proved two years later, at Petersburg; similar experiments have since been performed with equal success in the Netherlands (1837), and at Chatham, in 1838 and 1839, by General Pasley, especially to investigate explosion under water; the results have fully established the certainty and safety of these modes. In the Netherlands an inconstant but powerful Wollaston's battery, of 2¼ square feet effective copper surface, at Chatham, a Daniell's constant battery of 10 cells, each containing an effective copper surface of 230 square inches, were used for the experiments.

On the 26th Jan., 1843, a blasting of rock by this process was performed on a very large scale, when the Round Down was blown up in the neighbourbood of Dover. Cubitt, the engineer employed by the London and Dover Railway Company, in the construction of their line, deposited three charges, in all 18,000lbs. of powder, so that the middle one was 70ft., and the others each 55ft. from the extremities of the cliff. The powder was fired by means of 18 Daniell's and 2 common batteries of 20 pairs of plates, at a distance of

1000 feet, it having been previously ascertained that it might have been fired even at a distance of 3300 feet. (Probably a few Grove's or Bunsen's batteries would have answered equally well.) 300,000 cubic yards of chalk, weighing 600,000 tons, were set in motion at once, and the cliff was considerably lowered for the length of 500 feet.

It is of great importance that these results can be attained with perfect safety and at considerable distances (Basse, at Hamela, raised a piece of platinum wire to a state of incandescence at a distance of 4000 feet); as also that the conductor may be carried through the air, or on or under the surface of the earth, nay, even through water, without the action of the battery being thereby impaired. This mode of blasting may be more generally used since the adoption of small carbon and platinum batteries; the great expense having formerly been an obstacle, as the early experiments were performed with large deflagrators.

Jacobi, to whom we are already under such considerable obligations for his numerous experiments and theoretical investigations in this department of science, was employed, in 1842, in conducting a series of experiments for discovering the best mode of conveying hydro-electric currents for telegraphic purposes. In examining how far water might be substituted for a metallic conductor, he arrived at the important results given below. He first established a conduction of this nature between Oranienbaum and an arm of the Gulph of Finland, a distance of 5600 feet, one half through water, and the other through an insulated copper wire, ¾ of a line in diameter, which was carried over a dam, so that the entire length of the connexion was 11,200 feet. The electric current was excited by a Grove's battery, of 24 pairs, and a common voltaic pile of 150 6-inch plates. A zinc plate of 5 square feet was sunk in the sea from one pole of the battery, and at the opposite end of the connecting wire a similar plate was sunk in a canal joining the sea. Charcoal points were used for completing the circuit of the Grove's battery; these, and also a fine platinum wire, were made red-hot, and these phenomena appeared to be more intense than when copper wires were used as conductors. In a later experiment he employed a similar conduction, the distance in this case being 9030 feet, namely, from the winter palace of the emperor to the Fontanka, near the Obuchowski bridge. One of the conductors was a copper wire carried under ground, the other was the Neva itself, in which a zinc plate 5 square feet was sunk beneath the surface of the river. At the other extremity a similar zinc plate was immersed in a small pond, whose level was 5 or 6 feet above the Fontanka, from which it was separated by a flood-gate. The battery consisted of 25 small Daniell's constant batteries, by means of which, notwithstanding the great extent of water, all the galvanic and magnetic phenomena were produced. At Lenz's suggestion, a different species of conduction was tried between the same stations. A connexion was established with a point of the iron roof of the winter palace, which was connected with the ground by means of conducting rods, and the current was carried equally well along the moist earth.

6.) To the end of one of the wires fasten a small strip of gold or silver leaf, or of copper or zinc foil, or a small piece of extremely thin tin or lead, and establish a contact between any one of these and the opposite pole, or one of the plates connected with it, and combustion of the metal will ensue, attended with a hissing noise, and with variously coloured light. Gold burns with a blueish white light, and leaves behind a dark brown oxide. Silver burns with a bright sea green colour, and emits a greyish vapour. The combustion of copper gives out a blueish green flame, mingled with red sparks and a greenish smoke. Zinc burns with a dazzling white light and white vapour; tin with red sparks, and lead with a purple flame. This combustion of the metals is rendered still more vivid, by connecting one pole with mercury and placing the metal that is attached to the other pole in contact with the mercury.

7.) The most splendid phenomenon of this kind is the combustion of charcoal points. Pointed pieces of the residuum obtained from gas retorts will answer best, or Bunsen's composition may be used for this purpose. Put two such charcoal points in immediate contact with the wires of your battery; bring the points together, and they will begin to burn with a dazzling white light. The charcoal points of the large apparatus belonging to the Royal Institution became incandescent at a distance of $\frac{1}{30}$ of an inch; when the distance was gradually increased till they were 4 inches asunder, they continued to burn with great intensity, and a permanent stream of light played between them. Professor Bunsen obtained a similar flame from a battery of four pairs of plates, its carbon surface containing 29 feet. The heat of this flame is so intense, that stout platinum wire, sapphire, quartz, talc and lime, are reduced by it to the liquid form. It is worthy of remark, that no combustion, properly so called, takes place in the charcoal itself, which sustains only an extremely minute loss in its weight, and becomes rather denser at the points. The phenomenon is attended with a still more vivid brightness, if the charcoal points are placed in a vacuum, or in any of those gases which are not supporters of combustion. Instead of two charcoal points, one only need be used if the following arrangement is adopted: lay the piece of charcoal on some quicksilver that is connected with one pole of the battery, and complete the circuit from the other pole by means of a strip of platinum. When I have used a piece of well-burnt coke in the manner just described, I have obtained a light which was almost intolerable to the eyes.

These thermal phenomena happen not merely at the points, as in the experiments described above, but also in the battery itself, both the electromotors and the connecting liquid becoming heated, the elevation of temperature of these latter being much less than that of the connecting wires, because the transverse section of their conducting surface is much greater.

§ 515.

4.) *Physiological effects.* — The physiological effects of the hydro-electric current on the nerves and muscles of animals are essentially the same as those produced by frictional electricity, modified, however, in some degree, by the continuous action of the current; they are also characterised by the presence of some chemical influence, which excites the organs of taste and sight in a remarkable manner. Very small batteries are adequate to excite the organs of taste and sight, but a large apparatus is needed to produce any perceptible influence on the sense of touch, so as to cause the nerves and muscles of the human body to contract when it forms part of the circuit. These effects may be rendered almost indefinitely more powerful by increasing the number of plates, whereas the magnitude of the excited surface exerts *no perceptible influence* on them. Hence, to produce a shock, we should use the common voltaic pile, or one of Faraday's or Young's batteries (§ 506.), with plates of about 2 square inches. The most efficient batteries, with large plates, and even those of platinum and charcoal, which exhibit to perfection the remarkable phenomena of incandescence, seem almost totally ineffective when used to produce this other class of effects. This strongly-marked distinction in the capacities of batteries consisting of a number of small pairs of plates, and those which are composed of a few large pairs admits of a satisfactory explanation by Ohm's law. (§ 511.) In any case when it is desired that the current should exert a powerful influence on some bad conducting substance, the density of the electricity must be increased as much as possible by employing a great many pairs of plates, and thus the resistance offered to the conduction and transmission of the fluid through its circuit by the interposition, for example, of the human body, is more easily overcome: this end would not be attained by increasing the quantity of the electricity, which we might do, either by increasing the effective surface, or by using more powerful combinations, because, by either of these means, we should reduce only the resistance that we meet with in the battery itself, and that, compared with the resistance of the non-conducting substance that forms a part of the circuit is, after all, but very small. So, also, we can easily explain why these effects are rendered still more powerful, if that portion of the human frame which is enclosed within the wires be moistened with some liquid that is a good conductor: the effect is heightened still further, if large metallic surfaces, instead of merely the points of the wires, are brought into contact with the body: by either of these modes, the strong resistance which the human frame offers to the transmission of the electricity is much lessened.

Suppose we use a single pair of plates, whose electromotive power we will call 1, and that the resistance of the human body which forms a part of the circuit is 100 times greater than that of the pair of plates, then, by Ohm's formula, the effect of the current on the body may be expressed by the fraction $\frac{1}{1+100}=\frac{1}{101}$. Next use a battery consisting of 100 such pairs, and its effect will be represented by $\frac{100}{100+100}=\frac{1}{2}$, which is much greater than that of the single pair; now if we were to employ a single pair of plates with an electromotive force 100 times greater than that of the pair first spoken of, or, in other words, one whose resistance to conduction shall be 100 times less than that of the former; the effect of its current on the human frame would be only $\frac{1}{\frac{1}{100}+100}=\frac{1}{100.01}$ which is but very little more than that of the first pair, whose electromotive power we supposed to be only $\frac{1}{100}$th part of the power of the latter pair.

The following are a few of the principal experiments by means of which these effects of the voltaic current may be verified.

Experiments (1). *Galvani's fundamental experiment* deserves the first place in this list. Touch the nerve of a dead frog's spine and the muscle of one of his thighs with two different metals, *ex. gr.* with zinc and silver, or zinc and copper wires, bring their points into contact, and the frog's leg will become violently contracted. These muscular contractions will be repeated as often as the connection of the wires is re-established, and in young frogs especially they may be perceived even an hour after death. Bailey substituted with complete success the hind leg of the common grasshopper for that of a frog.

2.) *Imparting the shock to a leech.* Lay a silver coin, a five-shilling piece will do very well, on a larger plate of zinc, either metallically pure or amalgamated, and on the coin place a live leech. When he moves so as to touch the zinc, and thus establish a connexion between this metal and the silver, he will receive a shock, and will instantly recoil.

3.) *The nerves of taste excited in the human subject.* If the hydro-electric circuit be completed by the interposition of the tongue, one pole of a battery being placed in contact with the tip of the tongue, and the other pole being made to touch a moistened part of the face, the metal on the tongue will excite a peculiar taste, varying according as it conveys either + or − electricity; the former produces a sourish cool taste, but the latter causes a bitterish burning or alkaline taste; this is owing to the chemical decomposition of the saliva by the electric current in its passage. The effect may be produced by means of a very simple galvanic combination, namely, by laying a silver spoon and a polished strip of zinc one above and the other under the tongue, and then bringing the ends of the metals into contact. The sensation will be more powerful if a small battery of from 10 to 12 pairs of plates be used.

4.) *Excitement of the nerves of sight.* A peculiar flash or luminous appearance will be produced by bringing the poles of a voltaic battery to two parts of the body between which the eyes are situated, as, for instance, the corners of the eyelids; or a similar effect may be produced by holding one of the wires with a moistened hand, and planting the point of the other wire against the edge of the lid, or against a piece of tin-foil held over one of the eyes, which is to be closed. The phenomenon occurs on completing the circuit, and again in a lower degree when the connexion is broken. A similar but more feeble impression is produced by placing a silver spoon between the gums and one cheek, and a strip of zinc held in a like position on the other side, the circuit is completed by making the metals touch outside the mouth. The intensity of the flash is heightened by using a small pile of some 10 or 12 pairs, and establishing a connexion by means of the hand, the wire being brought against some moistened part of the face.

5.) *Influence on the organs of hearing.* Bring the poles of a small battery to the interior of both ears, and at the moment when the connexion is established, a slight shock will be felt in the head, and a roaring sound will be heard so long as the wires are held in place.

6.) *Muscular contractions and shocks of the nervous system.* To induce an electrical shock that shall be plainly felt, it is necessary to have a battery of at least from 10 to 15 pairs of plates; with a pile of from 50 to 100 pairs the shock is pretty strong, sufficiently so to cause violent shudderings in the fingers, arms, and even in the chest, besides occasioning in any sore places a sensation as if the skin were being pricked or burnt. On closely observing this effect on the nerves, three distinct stages in the process are readily distinguishable; first, at the moment when the circuit is completed, an electric shock is experienced; next, the continued action of the current causes a series of contractions rapidly succeeding each other; and lastly, when the connexion is broken, a less violent shock than before is felt. The shock of a voltaic battery may be distinguished from that of common electricity, inasmuch as the latter is felt far less deeply, affecting only the outer part of our organs, and being exhausted in a moment; the voltaic shock, on the contrary, penetrates farther into the system, propagating itself along the entire course of the nerves; this permanent action on the nerves is rarely perceptible when piles of fewer than from 40 to 50 pairs of plates are used. These physiological effects may be considerably heightened in intensity by connecting with the battery two metallic cylinders, called conductors, and grasping them with the hands well moistened in salt water. By using conductors, the voltaic shock can be communicated to a large number of persons if they join hands, after well wetting them in a saline solution. Since the most powerful effect is produced at the instant when the connexion is established, and when it is broken, the influence of the electric current is considerably increased by causing a rapid alternation in the completion, and breaking of the connexion. This is effected by means of a very simple contrivance, a copper disc being used for this purpose: the periphery of the disc is indented with teeth into which a metallic spring fits: this wheel is then connected with one pole of the battery, and the spring is connected with the conductor which the operator holds in one of his hands, his other hand grasping the other conductor which belongs to the other pole. The wheel is then made to revolve, and the connexion of the battery is alternately established and broken, and with every change the effect of the electric current on the human frame is renewed. Dry electric piles (§ 508.), even when the number of pairs of plates is considerable, do not produce any perceptible physiological effects.

The influence of the hydro-electric current on the nervous system has, in many instances, been applied successfully to the restoration of persons in whom animation was suspended. The experiments performed on human corpses, and on the dead bodies of the larger animals, are worthy of notice; by means of a voltaic pile, Aldini set in violent motion the feet of a corpse, caused the eyes to open and shut, and distorted the mouth, cheeks, and the whole of the countenance. Ure connected one of the poles of a voltaic battery with the supra-orbital nerve of a man who was cut down after hanging for an hour, and connected the other pole with the nerve of the criminal's heel: on completing the circuit, the muscles acquired a frightful activity, so that rage, despair, and anguish, with horrid smiles, were successively depicted on the countenance. Similar phenomena may be observed in experimenting on the head of a sheep, calf, or other animal, shortly after it has been killed. Tear off the claw of a crab or lobster, and send a hydro-electric current through it, and the claw will instantly contract; nail a neat's tongue to a table, send a discharge through it, and the contractions will be powerful enough to draw the nail.

§ 516.

5.) *Chemical effects.*—The chemical effects of the hydro-electric stream are indisputably the most important of all that are generated by either the simple voltaic arrangement or by the larger batteries. They were observed by Carlisle and Nicholson shortly after the original discovery of Professor Volta; Faraday's investigations have recently added most materially to our knowledge of this subject, and in particular, it is to him that we are indebted for detecting most of its laws.

To produce these effects the current must be conducted completely through the substance which is to be decomposed; as soon as the circuit is completed they will begin to be in operation, and will continue so until the connexion is broken. The bodies to be resolved must further be conductors of electricity, and their particles must be in such a condition as to move freely among each other: this latter requirement is fulfilled by bringing them into a liquid state either by dissolving or fusing them. The chemical influence is then exerted both on the electromotive fluids employed in the battery, and also on any liquids which form a part of the circuit through which the stream is sent. All chemically compound substances are not immediately resolvable by means of the electric current, as there are some whose decomposition is the consequence of a secondary action. This fact was first discovered by Faraday, who called all those bodies which can be immediately resolved by the current, *electrolytes*, and the elements into which they are resolved, *ions*, and the process itself *electrolysis*.

The electromotive force required to decompose the electrolytes varies greatly. A very feeble stream is sufficient to resolve iodide of potassium, whereas the decomposition of pure water can be effected only by the action of a powerful current, and the alkalies require the application of an extremely strong stream to resolve them into their elements. Decomposition may sometimes be effected even when a feeble current of electricity is employed, if aided by any chemical affinity, through which at least one of the elements becomes disengaged, or a new compound is formed. Even when the fluid exhibits no perceptible decomposition, it by no means follows that none takes place, as the galvanometer always shows the passage of the current through the fluid. The chemical action depends principally on the quantity and on the intensity of the electricity sent through an electrolyte, a matter that will in great measure be regulated by the conducting power of the latter.

The following results have been obtained experimentally, and are found to coincide with the deductions from Ohm's law: if the body to be decomposed has a very low conducting power, its electrolysis will be effected only by employing a battery consisting of a great many pairs of plates, and the number of plates must be increased the greater the chemical affinity which the elements of the electrolyte have for each other. In this case it is the *intensity* of the electricity which regulates the effect produced, whereas any increase in its quantity, obtained by enlarging the excited surfaces, and any diminution in the resistance to conduction offered by the battery itself, are equally inoperative for increasing the action. If, on the contrary, the electrolyte be a good conductor of electricity, the chemical decomposition will be perceptibly accelerated by increasing the excited surface of the electromotors, and by interposing a better conducting fluid between them: if we diminish the resistance of the electrolyte itself to conduction, the chemical action will be rendered still more intense: this may be done by lessening its length and thickness, and so increasing the intensity of the current sent through it.

Ritchie was led to believe, from a number of experiments which he performed, that the chemical effect of the current varied as the square root of the number of pairs of plates composing the battery. Hence it would be more advantageous to combine eight single voltaic pairs into two batteries of four times the surface, rather than into a single battery of eight pairs, for in this case the action of the former will be to that of the latter as $4\sqrt{2} : 1\sqrt{8}$, or as $2\sqrt{8} : 1\sqrt{8}$; *i. e.* as 2 : 1.

One of the most important discoveries was this, that in all decompositions of this kind, the elements into which the substances are resolved so arrange themselves on the surfaces of the metals which conduct the current in the electrolytes, that certain elements are invariably found on the one pole and others as constantly on the opposite. Thus oxygen, chlorine, iodine, and the acids, always collect about that metal which is connected with the + pole of the battery, but hydrogen, most combustible substances, the bases of the salts, and the metallic oxydes, range themselves on the metal which is attached to the — pole.

This has been attributed to some peculiar attraction and repulsion of the elements of the substance undergoing decomposition, which attractive and repulsive force proceeds from the poles of the battery along the wire or other conductor of the electricity to the fluid, and so brings about the decomposition of the body. Faraday is of opinion, that the force does *not* emanate from the poles, but that it resides in the substance undergoing resolution, and thus he accounts for one element's going to the positive, and the other to the negative end of the battery. He regards the poles of a hydro-electric battery as the points of egress and ingress of the electrical action, whence the influence which we designate the electrical current is propagated through the electrolyte; in accordance with this view he gave the following appropriate designations: The poles of the connecting wire in any fluid submitted to the process of electrolysis, he termed *electrodes;* that which goes from the + pole of the battery, *i. e.* the positive electrode, he distinguished as the *anode*, and the other or negative electrode proceeding from the — pole, he called the *cathode ;* an *ion* which deposited itself on the anode, he named an *anion;* such as arranged themselves on the cathode, he named *cathions.* It is not absolutely necessary that the electrodes should be metal, their surface may be air, water, or any other substance whatever ; all that is essential is, that the stream should pass through them into the fluid you wish to decompose.

Fechner, on the other hand, has attempted to explain the chemical effects of the electric current, on the hypothesis that they depend on the fundamental electrical forces. He assumes that the very same process is carried on between the elements of an electrolyte as goes on when two electromotors are brought into contact. Both elements are by him supposed to be in opposite electrical conditions as the result of their contact; they, therefore, attract each other, and are held in a latent state. When the connexion in a voltaic battery is established by means of an electrolyte, and before electrolysis commences, its elements will arrange themselves in the following order, by virtue of the electrical polarization emanating from the excited electromotors. (See § 505.)

$$+\,\text{Pole}\left[\begin{array}{l}(a\,.\,b)\,(c\,.\,d)\,(e\,.\,f)\\ (-\,+)\,(-\,+)\,(-\,+)\,(-\,+)\end{array}\right]-\,\text{Pole.}$$

Now to effect a separation of the elements *a* and *b*, the attractive force of the + pole on the negative particle *a* must exceed the force by which it is joined to + *b*. In such a case the particle *a* would either combine with the substance of the pole (or electrode), if the requisites for a chemical combination were fulfilled, or else by the action of the pole it would merely be deposited on it; a repulsive force would then be excited on the particle *b*, and an attractive one on *c*. These two particles would thus be brought nearer together; for an instant they would combine, but the progressive and overpowering action of the + pole would almost as quickly separate them, and thus the influence would be regularly transmitted through the entire stratum of the electrolyte lying between the poles (or electrodes). *b* and *c* change places in consequence of the influence of the pole; *b* and *d* are then rendered repulsive to each other, while the former attracts *e*, *d* is therefore driven towards the − pole, and *e* is attracted by the + pole, and so on. The same influence which has been assumed to emanate from the + pole, proceeds also from the − pole, only with this distinction, that it acts on the elements of the electrolyte in the opposite direction: electrolysis is accordingly carried on and supported by the simultaneous and corresponding action of both poles.

According to this theory, the permanence of the current is owing to the chemical decomposition and transmission of the elements, resulting in the first instance from their contact. The consequence is the same as would ensue if the electrolytes were merely conductors and not exciters of electricity; but the internal process is altogether different. The elements liberated by electrolysis propagate, according to this hypothesis, not that electricity which they derive from the metals, but their own antagonist electricities, for which they are indebted to their chemical combination. Since, however, this electricity neutralises the opposite electricities of the electromotors, a fresh excitation and discharge of electricity must be supposed to take place in all the metallic plates of the pile.

We have already remarked, that all compound bodies cannot be immediately decomposed by means of the current. Faraday, therefore, divides them into such as admit of *primary* and *secondary decomposition*. Those bodies which are decomposable directly by the electric current, *i. e.* the electrolytes, must consist of two ions, and must also render them up during the act of decomposition; but nitric acid and sulphuric acid are not electrolytes, because they are not composed of electro-chemical equivalents of simple ions, and can only be decomposed by a secondary action: in many of these cases, the electrolysis of water forms an important part of the process. New chemical combinations are often formed simultaneously with the decomposition of an electrolyte; the ions being in contact with each other at the moment of their evolution, favours their combining chemically. In many cases the elements combine chemically with the metallic electrodes or polar wires, whose surface thereby becomes altered, or the elements of the solvent may unite with those of the substance held in solution.

> This secondary action obtains most frequently in the decomposition of water and aqueous solutions. If gold or platinum be used for the electrodes, the oxygen will be given off at the + electrode, and the hydrogen at the − electrode; but if the + electrode be made of any base metal as *ex. gr.* zinc, no oxygen will be evolved there, for it will combine with the metal and form oxide of zinc. If the water contain any sulphuric acid, it will unite with the compound just named, and form sulphate of zinc. In an aqueous solution of iodide of potassium, the iodine will appear at the positive, and the hydrogen at the negative electrode: the potassium will unite with the oxygen of the water and form potassa. A solution of sulphate of copper in water while decomposing gives off oxygen at the positive electrode, and metallic copper at the negative pole, sulphuric acid being obtained in the liquid. The process may be conceived of thus, namely, that the metallic oxide is conveyed by the current to the negative electrode, and that it is reduced by the evolution of the hydrogen from the water; the oxygen and the acid, meanwhile, go to the positive electrode where the oxygen escapes in the form of a gas, if the electrode be of either gold or platinum, and the acid remains behind in the liquid; if, however, the electrode be of some base metal the oxygen and acid combine, as stated above, with the metal.

The regularity with which it was observed that the elements ranged themselves when bodies were electrolysed, some on one pole and others on the other, led to the formation of a new system of chemistry, known as *electro-chemistry*. Sir H. Davy, who was the first to make important discoveries in this department, was the founder of that system which Berzelius afterwards so materially extended and improved. This system proceeds on the assumption that the attractive force of opposite electricities is the fundamental cause of every chemical combination whatever; every compound substance, therefore, consists of one positively, and one negatively electrified element. Starting from this point, an attempt has been made to arrange all the simple substances according to their choice of the electrodes in a hydro-electric battery, so that the elements might stand in such order that any one combined with that which preceded it in the series would, on being electrolysed, go to the positive electrode, while the latter would go to the negative: in such an electro-chemical series, the first element will be that which is the most negative, and the last the most positive. On the same principle, the acid in a salt is regarded as its negative, and the base as its positive element, because, when subjected to the process of electrolysis, the base is found at the negative, and the acid at the positive electrode.

The electro-chemical order of the 54 simple substances as given by Berzelius in 1835, is as follows: oxygen, sulphur, nitrogen, fluorine, chlorine, bromine, iodine, silenium, phosphorus, arsenic, chromium, vanadium, molybdenum, tungsten, boron, carbon, antimony, tellurium, columbium, titanium, silicium, hydrogen, gold, osmium, iridium, platinum, rhodium, palladium, mercury, silver, copper, uranium, bismuth, tin, lead, cadmium, cobalt, nickel, iron, zinc, manganese, cerium, thorium, zirconium, aluminium, ittrium, beryllium, magnesium, calcium, strontium, barium, lithium, sodium, potassium. As has been observed already, it must not be supposed that the above has been absolutely determined to be the exact order of the simple substances, especially as the rank of but few of them has been ascertained by direct experiment: with regard to most it has been deduced from their chemical relations. The metals which precede hydrogen in this list are *electro-negative*, and such as come after it are *electro-positive*.

As we have described in the preceding paragraphs the principal phenomena which attend the electro-chemical decomposition of a compound body, we may now proceed to describe a few experiments by way of illustration.

First Expt. Decomposition of water. — Water is the substance whose electrolysis was first noticed, and as it was seen that its oxygen was invariably given off at the + electrode, or + pole, while the hydrogen was as constantly found at the — pole, the former received the appellation of the *oxygen*, and the latter that of the *hydrogen pole*.

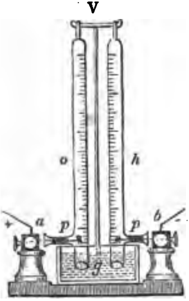
In consequence of the low conducting power of pure water, it can be decomposed only by means of the intense current obtained from a battery consisting of a large number of plates. Increase the conducting power by mixing some acid with the water, and its decomposition will be effected by means of a less powerful current; the action will be still further accelerated if the oxygen that is given off can combine chemically with the + electrode.

Water may be decomposed by means of a very feeble current, if the following arrangement is adopted:

Immerse a strip of amalgamated zinc into a glass of water impregnated with a little sulphuric acid, no action of the liquid on the metal will be visible; immerse a strip of copper also, it too will be unaffected so long as the two metals are kept asunder, but when those parts of the zinc and copper which stand above the surface of the water are brought into contact, or are connected by means of a wire, little bubbles are seen to deposit themselves on the copper; these bubbles contain the hydrogen set free by the decomposition of the water, the oxygen at the same time passes on to the positive metal (the zinc) and oxydises it.

If the electrodes of a battery be of platinum or gold, on plunging them into acidulated water its elements will be given off according to the laws of electrolysis, the oxygen at the + electrode, and the hydrogen at the — electrode. Both the gases rise in the form of minute bubbles in the water, and may be taken off in small receivers either separately or together, so as to make the detonating oxyhydrogen gas. A very convenient piece of apparatus for this experiment and other similar decompositions has been contrived by Mitscherlich; it is represented in *fig.* 192.: *o* and *h* are two glass tubes about ½ an inch wide, and from 6 to 8 inches long, graduated and closed at top; at *p* there is a side tube through which a platinum wire thrust through a cork reaches into the tube, and serves as a pole of the battery. The action of these electrodes is materially increased by making them terminate in a small brush of fine platinum wires; their efficiency is still further heightened by covering these with a little spongy platinum. Fill the glass tubes with acidulated water, invert them, and plunge their open ends under the same water with which the glass vessel *g* is filled; connect the platinum wires with the mercurial cups, or the binding screws *a* and *b*: the tubes should be so attached to the upright V *g*, that they

Fig. 192.



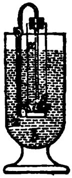
may hang near together. If now the + wire be placed in the mercurial cup *a*, and the negative wire be put in *b*, the circuit is completed, and the gases will begin to be given off at the two platinum electrodes *p p*, in such a manner that 1 measure of oxygen will be collected in the tube *o* in the same time as 2 measures of hydrogen will accumulate in *h*.

Second Expt. Decomposition of a neutral salt. — Fill the tubes of the apparatus just described above with a solution of any neutral salt, as *ex. gr.* with a solution of sulphate of sodium, or nitrate of potassium, which may be coloured blue with some vegetable pigment, such as tincture of violets or iris petals; then the acid being given off at the + electrode, the liquid will become red and the alkali at the — electrode will tinge the liquid green. Transpose the poles so that the negative electrode shall be in the red fluid, and the positive in the green, after a short time they will both recover their original blue tinge, and then that which had before been red will become green, and the green will turn to red.

Third Expt. Regular deposit of a metal from the solution of a metallic salt. — It is in this kind of electrolysis especially that the de-oxydizing influence of the hydrogen is observable, which is given off at the negative electrode, whilst the oxygen of the metallic oxide is simultaneously developed with it, and the two gases form water; the positive metal is consequently thrown down in a regular deposit on the negative electrode. These decompositions are effected by means of very feeble currents; for if their energy is considerable, the reduction will not be brought about with sufficient rapidity by the hydrogen, and a portion of the metal will be thrown down in the state of oxide.

The apparatus represented in *fig.* 193. will be found convenient for effecting such deposits of the metals by means of the current from a simple battery. *a* is a glass tube a few inches in length, and from ½ an inch to an inch in width, a piece of bladder is tied over its mouth, and the whole is suspended in a larger cylindrical vessel, *b*. Pour the metallic solution (sulphate of copper, acetate of lead, muriate of tin, or nitrate of silver will do) into the glass *a*; let the outer glass contain a solution of chlorate of sodium, or dilute sulphuric acid; then into the metallic solution immerse the wire *p* of a negative metal, as *ex. gr.* a silver, gold, or platinum wire, and in the outer liquid plunge a strip of amalgamated zinc *z*, a connexion will be established between the two metals, and a hydro-electric battery will have been formed, consisting of two exciting fluids, both of

Fig. 193.



which will be decomposed by the current passing through them: after the battery has been some time in action, the reduced metal is seen on the negative wire frequently in a crystalline form, and it will continue to be deposited until the entire quantity contained in the solution has been conveyed to the negative electrode.

A similar result is obtained by surrounding a piece of zinc with brown paper or linen, and immersing it in dilute sulphuric acid; then place this electromotor in a glass containing a solution of sulphate of copper, and connect a piece of some negative metal with the zinc; a copper, silver or gold coin will answer the purpose well, and will in a short time be completely coated over with copper.

The chemical metallic vegetation known by the name of *lead*, and *tin trees*, and the *silver tree*, or *arbor Dianæ*, are strictly analogous operations, as in these metallic solutions a bit of zinc is immersed on which the first atoms of metal are deposited in the first instance, through the action of chemical affinity, these atoms being in contact with the + electromotor, form a simple voltaic arrangement, on the continued action of which the further deposition of metal depends.

In the examples already given, the electromotors themselves discharge the functions of electrodes; but the like results may be obtained from either single or compound batteries, by conducting their wires into a glass containing the metallic solution to be electrolysed: in this case no hydrogen will be given off at the — electrode; but instead, there will be formed a regular deposit of metal.

Fourth Expt. Reduction of the alkaline metals. — As the alkaline combinations display the most powerful chemical affinities, they require the strongest electric currents to effect their decomposition. Sir H. Davy first succeeded in reducing them in 1807, and so caused the alkalies to be transferred from among the simple substances with which they had previously been ranked: many other philosophers have since that time effected their decomposition. The experiment may be conducted in the following manner, by means of a tolerably strong battery, the requisite intensity being imparted to the electric current mainly by constructing the battery of a sufficient number of pairs of plates: lay a thin piece of caustic potash slightly moistened on a disc of silver or platinum connected with the + pole of a battery, and touch the surface of the alkali with the silver or platinum wire of the — pole; the alkali will begin to fuse at the point of contact, and soon a small globule of the reduced potassium conspicuous by its metallic lustre will be seen on the wire: to secure it from oxydation, which would other wise commence almost instantly, the potassium should be put in petroleum, or Barbadoes tar.

By availing ourselves of the affinity of mercury, the alkalies may be reduced with apparatus of mean power: according to Pfaff's and Herschel's experiments with piles of not more than 10 pairs of plates. To perform this experiment, scoop out a pretty deep hole in a piece of moistened caustic potash, and fill the cavity with mercury; lay the potash on a platinum plate which is connected with the + pole of the pile, and put the quicksilver in contact with the — pole whose wire must be either iron or platinum, on it the mercury will speedily be deposited as a solid amalgam. According to Berzelius, it is best to pour a concentrated lye of caustic potash, the solution being such a saturated one, that it shall contain some potash undissolved, over the mercury, which should be held in an earthenware saucer, then conduct the negative wire to the mercury, and the positive platinum one into the lye; the quicksilver will become thicker and thicker, and small metallic crystals of the amalgam of potassium will be formed, their figure being apparently cubical.

Sodium may be decomposed as readily as potassium, by the aid of mercury, if we use some of its salts, especially either sulphate of sodium, or chlorate of sodium; the alkaline earths may also be reduced by means of mercury, which combines with their metallic radical so as to form amalgams; the earths will, however, require rather powerful batteries.

By this process we may obtain the *amalgam of ammonia.* Berzelius's method of obtaining this singular substance is the following. The experiment may be performed, he says, in the same manner as the reduction of potash, with this difference only, that a concentrated solution of sal ammonia should be poured on the mercury, which will begin to swell up and continue to do so until it attains from 5 to 6 times its original volume, the metal will acquire a silvery whiteness, and will be of the consistency of butter. This amalgam may be procured in larger quantities, and of a drier form, by scooping out a hole in a piece of sal ammonia, moistening it with a little water, and pouring a small quantity of quicksilver into the cavity, then connect the mercury by a platinum wire with the — pole of the battery, a similar wire being made to join the moistened sal ammonia with the + pole, passing as near as possible to the quicksilver without coming into actual contact with it. The globule of quicksilver will increase gradually till at last it extends far beyond the cavity which at first contained it. This amalgam is procured most copiously and readily, if the quicksilver employed in the last experiment to accelerate the reduction be combined with a very minute portion of potassium or sodium, and the battery be then arranged as described above.

Fifth Expt. Transmission of the decomposed elements through substances which have a low conducting power, and through liquids which have a chemical affinity for them. — The transmission of the substances through porous bodies of low conducting powers, and through fluids with which they might have been expected to combine chemically, so that they arrive at the respective electrodes of the battery is certainly one of the most extraordinary phenomena of electrolysis.

The third experiment may serve as an illustration of the transmission of the elements through porous bodies, as bladders, earthenware, and the like; for, on referring to that experiment, it will be seen that the current and the electrolysis of the metal are transmitted through the bladder. This process may be rendered visible by filling the glass tube with a solution of sulphate of sodium, and the outer glass with water, then colour both the liquids blue, with some vegetable tincture; and that which contains the negative metal will become green, and that in which the positive metal stands will be red. The like obtains in those batteries which have two fluids separated by means of a porous earthenware cell.

The products obtained by the decomposition of the substance electrolysed, pass to their respective poles, through different liquids which communicate with each other, as may be shown thus:

Fill two small glass vessels with the liquids to be decomposed; connect the vessels by means of some threads of cotton. In like manner interpose another vessel, also containing some decomposable liquid, between the first two; connect it with them by thread; into the outer vessels bring the poles of a galvanic battery, and the following results will be observed.

In whatever manner you may have distributed the fluids in the different glasses, after some time their electro-negative element will have accumulated in the glass that contains the positive electrode, and the positive element in that which is connected with the negative electrode. Immerse, *ex.gr.*, the positive wire in a solution of sulphate of sodium, and the negative wire in pure water, the acid will collect about the former and the base about the latter: the base must therefore have been carried over into the other glass. This interchange of the substances may be made apparent by dyeing the liquids in the two vessels blue, with tincture of violets.

The acid or alkaline elements, in their passage through the middle glass, do not in the least degree affect the liquid it contains.

This transmission obtains only when they have to pass through a fluid with which, but for the voltaic pile, they would form a solution.

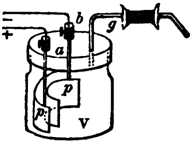
§ 517.

Faraday's comprehensive investigations led him to discover two important laws in electrolysis, the accuracy of which has been confirmed by the subsequent researches of Professor Jacobi.

He found that, "*the chemical power of a current of electricity is in direct proportion to the absolute quantity of electricity which passes*," or, expressing it according to Ohm's law, "*to the quantity of electricity which passes during the process of decomposition through the transverse section of the battery.*" Hence it follows that the same quantity of electricity will always decompose an equal portion of the same substance: so the quantity of the elements obtained in any given unit of time will depend on the density or intensity of the current employed. Hence if the intensities be twice, three times, or *n* times greater, twice, three times or *n* times as much of the body electrolyzed will be decomposed. If the mass and density of the electricity emitted, that is to say, if the electromotive power and its intensity, remain unaltered, the effect of the current or the quantity of the substance decomposed will be the same; but if one or both of these factors be altered, the degree of chemical decomposition will be proportionally affected.

If we take into account the time required to produce a certain effect, we may use any substance to measure the *intensity* of the electric current, if it possesses the following properties, viz. that it is easily resolved, that its structure is perfectly uniform, and that the products yielded by its decomposition admit of being readily measured; the reader will bear in mind that the *quantity* of electricity discharged in a current is measured by means of a galvanometer. Faraday first constructed an apparatus for measuring the intensity of the electric current, and gave to his invention the name of a *volta-meter.* The electrolyte which best fulfils all the requirements is water, and any arrangement in which a stream of electricity is made to decompose it, if furnished with the means for measuring the quantity of gas thus generated, may be regarded as a volta-meter.

Fig. 194.



In *fig.* 194. we have represented a very simple and efficient kind of volta-meter. V is a glass cylinder capable of containing from two to four ounces of water: it is covered with a well-polished piece of plate-glass, (the lid may, however, be made of metal, if care is taken to insulate the wires *a* and *b*, which are carried through it). *p p* are the two electrodes, which consist of two plates of platinum or iron placed parallel, and as near together as possible. The wires to which these plates are soldered pass air-tight through the lid, and are connected by two binding screws with the wires of the battery. *g* is also a glass tube, fixed air-tight in the top of the cylinder; it is meant to be placed under a graduated glass tube in which the oxy-hydrogen gas is taken off as it is liberated by the decomposition of the water. According to Poggendorf's experiments, if the electrodes be of platinum, it is best to mix the water with sulphuric acid, but if of iron, it is advisable to add, instead, a tenth part of caustic potash.

The other law, equal in importance to the first, is this, "*the amount of electro-chemical action is a constant quantity, i. e. would always be equivalent to a standard chemical effect founded upon ordinary chemical affinity,*" in other words, *the quantities of the products which any stream of electricity disengages by resolving various electrolytes are to each other in the same ratio as that in which they combine chemically.* This is known as *the law of definite electrolytic action*, in accordance with which Faraday has called those masses of bodies which combine with equal definite quantities of electricity *electro-chemical equivalents.* From the above law we may deduce the following important conclusion, that, in consequence of the proportionality that subsists in all decompositions effected by the same quantity of electricity, reckoning according to the atomic weights of the bodies resolved, *the atoms of all substances whatever must take up or hold, in an equally latent state, equal quantities of electricity.*

From a number of experiments originally performed by Faraday, and since repeated and modified by Pfaff, it was ascertained, that for every atom of water decomposed by a hydro-electric current in a volta-meter, one atom of any other electrolyte or ion would be resolved by the same stream in its passage through another cell containing it. Thus Faraday found in transmitting a current of electricity through a volta-meter which had an amalgamated zinc plate for its positive and a platinum plate for its negative electrode, that whilst one part by weight of hydrogen was evolved at the latter, 32·3 parts of zinc were dissolved at the former. But the equivalents of hydrogen and zinc are to each other as 12·48 : 403·23, or as 1 to 32·3. The current would produce precisely the same effect if conducted through any similarly arranged apparatus, *ex. gr.*, in a single pair of plates of amalgamated zinc and copper, or in a compound voltaic battery, for every equivalent of hydrogen that is evolved, one equivalent of zinc would be dissolved, so that the consumption of the metal would be always equivalent to the degree of electrolysis reached.

§ 518.

The power of the electric current to effect chemical decomposition manifests itself, as has been already remarked, equally in every member of a voltaic pile. This chemical action exerts a perceptible influence on the effect of the current generated by a hydro-electric battery; its influence being greatest on those batteries in which either a dilute acid or some saline solution is employed as the exciting liquid to act upon the metals. These batteries in consequence of their combination possess in the first instance but a feeble force, for the same fluid is in contact with both the electro-positive and the electro-negative metal, consequently the electromotive power of the two metals is similarly though unequally impaired; their influence therefore in generating the current corresponds to the difference in the electromotive excitement of the two metals. (Comp. § 505.) The elements of the liquid, too, which accumulate about the metals tend to diminish still more this electromotive difference. The hydrogen, the bases, or the metallic oxydes collect about the negative metal, whilst the oxygen, the chlorine, and the acids gather around the positive metal: the former is therefore coated with positive substances: it is thereby polarized and rendered less negative, and the latter by oxidation becomes less positive: in proportion as these changes are brought about in the electromotive fluids, and in the metals on which they act, the difference of tension will be diminished and the current will be enfeebled. Fechner's opinion is, that the diminution in the fluid's conducting power that attends its decomposition contributes in the highest degree to reduce the strength of the current.

These influences tell less powerfully on Daniell's, Grove's, Bunsen's, and the other batteries of more modern construction, in which each electromotor stands in contact with a fluid that excites it in a manner, the antagonist of that in which the other electromotor is excited by the fluid in contact with it. (Comp. § 505.) Hence the initial tension is greater than in such batteries as have but a single fluid: again the products obtained by decomposition diminish but little, or not at all, the difference of tension between the electromotors, as will be seen from the following considerations. If some sulphuric acid but slightly diluted be used in one of these batteries to act upon the amalgamated zinc, the oxide of zinc formed by the oxygen which is given off, is dissolved as rapidly as it is produced by the sulphuric acid that is in contact with it, so that the surface of the zinc remains unchanged; the electromotive fluid in the meanwhile becomes gradually converted into a solution of sulphate of zinc, which, as both Pfaff and Poggendorf ascertained, is nearly or quite as effective as the sulphuric acid; the electromotive properties of the zinc are therefore but little, or not at all, impaired by the continued action of the battery. In Daniell's battery, in which a solution of sulphate of copper is made to act on the copper, the process of decomposition is similarly advantageous; as the positive hydrogen emitted at the copper reduces the oxide of copper formed simultaneously with it, and which deposits itself as the pure metal on the negative copper surface. The electrical tension of the apparatus is therefore maintained at the same point, so long as care is taken that the solution of copper shall be a saturated one. In Grove's and Bunsen's batteries, where concentrated nitric acid is used to act on the platinum and carbon, these electromotors are not polarized and enfeebled by the hydrogen given off at them, because at the very instant it is generated, it combines with one equivalent of oxygen from the nitric acid and forms water, and a corresponding portion of nitrous acid escapes as a gas; thus, as Schönbein expresses it, the platinum, and by analogy the carbon also, become *depolarized* and relatively exalted in their electromotive functions. To this the more recent batteries are indebted for their superiority over the older ones, since the effect of their current is for a length of time unimpaired, they are therefore fairly entitled to the appellation of *constant batteries.*

§ 519.

Within the last few years the decomposition and reduction, by means of the hydro-electric current, of metals held in a state of solution, has led to several important discoveries which have been variously applied to industrial purposes. Such are the arts of *electrotyping* or *galvanoplastic*, *galvanography* or *electrography*, and *electro-plating.*

Electrotyping was simultaneously (1839) invented by Jacobi, of Petersburg, and Spencer of Liverpool. By this process copper casts are obtained of objects. It was observed that in a Daniell's battery a regular deposit of copper was formed on the negative metal by the secondary action of the solution of sulphate of copper in the course of the electrolysis; an object a cast from which was desired, was then made to discharge the functions of the negative electromotor in one of these batteries, and the molecules of copper accumulated on it in a compact mass of uniform density; some contrivance being adopted that after the desired thickness of metal had been attained, the whole might be removed without injury; when every elevation and depression, nay, even the most minute features of the original, were found to be depicted on the copy. Instead of using the object itself as an electromotor, an earthenware cell containing the solution of copper may be used as the negative electrode, and by conducting the stream of electricity through it, the deposition of the copper will be obtained as readily as before.

Fig. 195.

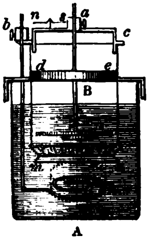


Fig. 195. represents a very simple electrotype apparatus. A is a glass cylinder in which the mould from which a cast is to be obtained is placed; the width of the cylinder will depend on the dimensions of the object. B is a narrower cylinder, also of glass, suspended on the former by means of a metal ring, *d e*, to which are fixed three strips of metal. The mouth of this cylinder *m n* is closed by tying over it a bladder or piece of thin parchment. The strip of copper or brass, *b c*, has two binding screws, *b*, *a*, (if both are on one side it is better) by which the wires are secured, whose lower extremities act as the electromotors. An amalgamated zinc-plate Z is suspended in the inner vessel: this is the positive metal. The body *k* from which a cast is to be got is laid on the spiral in which the wire *b k* terminates; the model is of course the electromotor. The outer glass, A, contains a concentrated solution of sulphate of copper, which is kept in a saturated condition by hanging in it a muslin bag filled with small crystals of sulphate of copper. Water slightly acidulated with sulphuric acid, or a solution of common salt, is used as the exciting liquid to act on the zinc in the inner vessel B; care should be taken that the liquids stand at the same height in both vessels. The arrangements just described may, without injury, be inverted, that is to say, the zinc with its liquid may occupy the outer cylinder, and the mould with the solution of copper may be in the inner one. It is obvious, from the description given of this apparatus, that it constitutes a simple battery with two exciting liquids in which the body to be coated with copper acts as the negative electromotor. The strip *b c* of copper or brass renders the circuit complete, the electric stream passes from the zinc Z to the mould *k*. If you wish to conduct the process in a jar or cell, you must pour into it a little solution of sulphate of copper; the model must in this case be the negative electrode, and a plate of copper of about equal dimensions will serve for the positive electrode. Let both be placed parallel to each other; the electric stream to be sent through them is obtained from a constant battery of from 2 to 6 pairs of plates; the model is to be connected with the negative, and the copper-plate with the positive pole of the battery. In this case the plate of copper which acts as the positive electrode will be dissolved by the sulphuric acid that is liberated in exactly the same proportion as the copper is precipitated on the negative electrode, that is, on the object from which the cast is to be got: the solution of copper is thus maintained at the requisite strength.

The following particulars must be attended to, in order to obtain good electrotype casts. The surfaces of the original should be good conductors of electricity, and especially they must not consist of any metal or metallic coating which would be dissolved by the solution of copper, or for which it has any chemical affinity; iron and steel are consequently unsuitable. It is by no means necessary that the model should be of metal; it may be of gypsum, stearine, wax, wood, or of any similar non-metallic substance, only the surface to be modelled from must receive a metallic coating; fine plumbago dust, or a thin film of silver, or bronze powder, laid on with a camel's hair brush, will answer well. In taking casts from coins or other metallic objects, on which it is undesirable to have any metallic deposit, it will be advisable to do them over with wax dissolved in turpentine. It is clear that in every electrotype cast, the elevated portions of the original will be depressed, and the depressed will be elevated. To obtain an exact facsimile of the original, the first cast must be used as a matrix, on which a deposit of copper must be thrown by the electrotype process, and the copy desired will be produced. Engravings on copper-plates have been multiplied by this means, and the copies are equally serviceable for printing from as the originals. M. Von Kobell has obtained pictures from designs on copper and silver plates, the effect of which closely resembles that of drawings in Indian ink.

The electrical stream by which the copper is thrown down, must not be too strong, or the coating of copper will not be sufficiently thick and tenacious; it is of great importance that the current should be of uniform strength, for which reason it is best to use a Daniell's or some other constant battery, that can be regulated by a galvanic compass (§ 512.); the battery *fig.* 195. is furnished with a magnetic needle *ns* placed on the strip of metal *bc*. The constancy of the strength of the current is best maintained by keeping up the solution of copper in a saturated condition, which may be effected either in the manner named in describing the apparatus, or as has been already shown in § 505.

We have a remarkable illustration of the perfect accuracy of an electrotype copy, owing evidently to the extreme minuteness of the particles of copper, in the fact that an electrotype copy of a Barton's Iris-button (§ 327.) produces as fine an effect by the prismatic interference as the original itself.

Electrography or *galvanography*, which was first discovered and applied by Osann, depends on the opposite effect of the electric current to that on which electrotyping rests. In this process the resolving power of the current is used to bite in figures and drawings on a copper plate, which is placed in a cell, and acts as the positive electrode; the marks on the plate are made by the deposit of sulphuric acid; all those parts on which it is not intended to act are therefore coated over in the same manner as in preparing the ordinary mezzotint engravings.

Electroplating is, properly speaking, only a modification and extension of electrotyping, inasmuch as it consists in covering metallic objects with a coat of solid gold, silver, platinum, copper, zinc, &c., of any thickness that may be desired. De La Rive first showed the application of galvanic electricity to this purpose: Dr. Böttger introduced some alterations in the details, which have been still farther simplified by Dr. Elsner. In the main it consists, like the electrotype, in covering with one or other of the metals named above some object which acts as the negative electromotor in an apparatus resembling that depicted in *fig.* 195.; the object to be electro-plated is immersed in a solution of the metal with which it is to be covered; this solution exerting on it an electromotive influence, so electrolyzes it by the current which is generated, that the metal disengaged from the solution is regularly thrown down and adheres firmly to the immersed body. Elkington's and Recolz's method, which has come to be generally adopted, differs from that just described in carrying on the transfer of the metal in a distinct cell. According to their plan the metallic solution is contained in a vessel of glass or earthenware, the size of which is proportioned to the dimensions of the object to be gilt or silvered. Immerse the object completely in the fluid, and connect it with the — pole of a constant battery of from 2 to 6 pairs of plates; it will thus form the negative electrode; suspend a plate of the same metal as is held in solution and of corresponding size with the object you desire to cover opposite to it in the liquid, and it will act as the + electrode. Any gilt or silvered article may be deprived of the metal with which it is coated by using it as the positive electrode and a similar piece of metal for the negative electrode; the plating will thereby be dissolved and be transferred to the latter. Solutions of the cyanide of the various metals are most commonly employed for this purpose; Dr. Hänle says the simplest mode of obtaining them is to pour an aqueous solution of cyanide of potassium (1 part of the latter to 10 of water) into a glass, in which suspend the metal, rolled as thin as possible, as the positive electrode, and at the distance of a few inches hang a copper wire as the negative electrode, taking care that it shall not sink more than ½ an inch below the surface of the liquid. Keep the solution at a temperature of about 100°, and in the course of 24 hours the electric current generated will have dissolved the metal: when the tip of the copper wire which acted as the negative electrode begins to be covered with a deposit of the dissolved metal, the solution is strong enough.

> The tinning of iron, steel, and cast-iron must of necessity be highly important for many purposes connected with the arts, and we may even anticipate the application of the process to protect fire-arms and ammunition from the action of weather.
>
> On this principle Becquerel conducted his experiments for obtaining in a crystalline form many bodies which had not previously been procured in that state. For this purpose a very delicate stream was conducted by fine wires into the fluid that was to be decomposed; on which after a considerable time, extremely minute particles were deposited in the form of beautiful crystals. Batteries such as that represented in *fig.* 193. will be found well suited for this experiment.

If a feeble current be applied to polished plates of platinum, steel and silver, by using them as electrodes, and immersing them in an electrolytic fluid, certain figures will be visible on them, called after their discoverer *Nobili's Electro-Chemical Figures;* the best solutions are those of acetate of lead, acetate or sulphate of copper, and acetate or chlorate of manganese; using then a polished plate of any of the three metals named above as one electrode, take a fine-pointed platinum wire as the other electrode, and bring it within one or two lines of the plate. The elements

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NOTE. — Mr. Walker has succeeded in reducing the *alloys* by voltaic electricity. His process is "to prepare a strong solution of cyanide of potassium, and commence electrolyzing it, by means of a copper anode; as soon as copper begins to be dissolved, the copper anode is removed, and its place supplied with one of zinc; after the action has continued for some little time, brass will be liberated on the cathode. The solution is now ready for use, and is operated upon by two or three Daniell's cells, and with a brass anode. By similar means alloys of gold and copper, or gold and silver may be deposited." — *Athenæum*, June 28. 1845.

obtained by the decomposition of the liquid will be deposited on the metal plate, generally in the form of concentric circles whose centre is exactly opposite to the point of the wire; their colours are various, very much resembling Newton's prismatic rings (§ 327), and so firmly fixed that they cannot be removed even by washing the metal with nitric acid. It has been remarked that with regard to many of the solutions (*ex. gr.* acetate of lead, acetate and chlorate of manganese), the figures are more beautiful if the plate is used as the + electrode, whereas with others (as, *ex. gr.*, acetate of copper) they are most brilliant if the plate is the – electrode. After a figure has been formed reverse the poles and it will gradually vanish; if the action be continued the opposite electrical figure will appear.

The above remarks may be illustrated by the following experiments:—

First Expt. According to Fechner, Nobili's figures may be produced by the feeblest current of a simple voltaic battery; lay a small plate of polished platinum or steel in an earthenware saucer, and pour over it a solution of acetate or sulphate of copper to the depth of a few lines, and touch the plate with a pointed strip of zinc the other end of which is in the fluid.

Second Expt. These figures will be obtained with increased brilliancy and beauty by using a constant battery of from two to six cells. Then, according to the solution employed, connect the plate with either the + or – pole of the battery, and bring the pointed platinum wire which conducts the electricity of the other pole to within a couple of lines of the plate. As soon as the electric circuit is completed the action of the platinum point commences and rapidly extends itself over the whole plate.

§ 520.

Hydro-electric currents are capable, not merely of bringing about chemical combinations and decompositions, but also of impeding such changes as, according to the ordinary laws of affinity, would ensue in a mode exactly opposed to the tendency of the current. Thus to guard a metal against the chemical action of an acid or a saline solution upon it, all that is necessary is to place it in contact, or to combine it with some other metal in the fluid, which may act as the positive electromotor when in contact with the metal you desire to protect. The oxydizing and dissolving elements of the fluid are deposited on the + metal, whilst only the positive elements are given off at the – metal. In this manner iron, copper, tin, lead, and silver are secured by means of zinc against the chemical action of sulphuric, nitric, and muriatic acids, as well as gold and platinum against the dissolving power of nitro-muriatic acid. Sir H. Davy successfully applied this principle in the means he employed for protecting the copper bottoms of vessels against the corroding influence of the salt-water; he connected plates of zinc, cast or wrought-iron, with the copper sheathing to the extent of from $\frac{1}{120}$th to $\frac{1}{104}$th of its entire surface.—Sometimes disadvantages are found to attend from the deposit of positive elements on metallic surfaces, as, for instance, leaden water-pipes occasionally become choked at the joints by the deposit of lime held in solution in the water.

Third Expt. Lay a piece of iron or copper plate in an earthenware or glass vessel, and pour on it some diluted sulphuric acid; the metal will be violently acted upon by it and dissolved. Now touch it with a piece of zinc, and the chemical action on the first metal will be suspended, being transferred to the zinc, and until it is wholly dissolved the copper will not again be acted on.

§ 521.

Lastly, from the action of these currents, generated between the polar wires and the elements of an electrolyte, there arise peculiar movements which, from their origin, are called *electro-chemical movements*. These phenomena were first observed several years ago by Ermann, and have since been more closely investigated by Herschel, Pfaff, Runge, Fechner, and others. To render these movements visible, pour the liquid that is to be electrolyzed on some mercury, introduce the electrodes of a voltaic battery, and, according to the chemical character of the fluid, the currents will be generated from the + or the − wire, sometimes from both; their course is sometimes rectilinear and at others curvilinear.

These phenomena may be observed with voltaic piles of from 10 to 20 pairs of plates, or with constant batteries of from 2 to 4 cells; with many fluids indeed, very small single batteries will be sufficient.

The following are the principal results to be noticed in performing these experiments:—

Pour some acid, *ex. gr.*, sulphuric acid, slightly diluted, on mercury, and the metal will be repelled by the + pole; but if any alkaline solution be added, it will be attracted by the same pole.

Immerse the negative wire in the quicksilver on which some alkaline solution rests, whilst the positive wire does but just touch the metal, and it will instantly collect about the — pole, and recede from the + pole. Establish the contact of the mercury again with both the poles; the same effect as before will ensue, so that there will be an alternate contraction and expansion of the metal. If an acid be used, the same pulsations occur on plunging the positive wire into the mercury, the negative wire only just touching its surface.

Runge says, that the following electrochemical motions may be induced by a simple voltaic arrangement: — Pour a concentrated solution of common salt on quicksilver, and lay very carefully a small crystal of sulphate of copper on the middle of the mercury, and in a little while the bright surface of the metal will be covered over with a film. Now touch the quicksilver, by piercing the solution that covers it with a smooth iron wire; the film will be rent asunder, then it will entirely disappear, and an electric current will be generated that will impart a rotatory motion to the crystal, which will grow less and less until it ceases to be visible.

§ 522.

The acquaintance we have now gained with the varied effects produced by the hydro-electric current will enable us to judge which will be the best adapted to serve as a measure of its strength. Fechner, who, by his admeasurements of voltaic currents, has gained so thorough and comprehensive a knowledge of the subject, gives the following estimate: —

He says that, in consequence of the unequal and inconstant degree of excitability in organised beings, the *physiological effects* of the voltaic current are by no means calculated to give us an accurate measure of its strength.

The *excitation of heat*, as shown in the incandescence of the wires, affords us a high, but by no means sufficient degree of certainty in comparing currents; and is applicable to powerful batteries, but must necessarily fail with regard to such as have but a feeble current.

The *chemical effects* of the current, and especially its decomposition of water, supplies us with an extremely accurate and invariable standard for estimating the force of the current, as regards both the quantity and intensity of the electricity. We may either compare the quantities of gas given off in the same time, or we may notice the times requisite for generating an equal quantity of gas. The voltameter, described in § 517., is an apparatus suited to this mode of measuring the current, and has been thus used, especially by Faraday: it is not, however, free from some serious defects. It cannot be applied to a simple galvanic arrangement, because water is dissolved so slowly by it that the product obtained would be imperceptible, even after the lapse of a considerable time. This method is consequently limited to compound batteries, and even when applied to them, it is attended with this inconvenience, — that all experiments conducted on this principle require a longer time than the other methods do, to furnish us with results that can be compared. Again, in proportion to the inconstancy of the electric current is the uncertainty and irregularity in the results obtained; and it is notorious that the stream of electricity is very variable in all the old one-fluid batteries.

There remain only the *magnetic effects* to be estimated, and in them we shall find all the requisites combined which we can desire in an exact measure of the force of the current. The deviation of the magnetic needle, mentioned above at § 512. as the fundamental effect, serves as a gauge by which to measure the most powerful and the feeblest streams, by allowing the former to act directly on a common deflecting needle, while the latter act on the magnet of a multiplier.

Magnets may serve in various ways to measure the force of electric currents. Either the deviation itself is observed which the needle makes through the influence of the current upon it; or the arc is measured through which a needle suspended in a Coulomb's magnetic torsion balance (§ 456.) has to be turned back, after the operation of the current upon it in order to bring it to the same place again; or, lastly, the time is sought which the same needle requires when subjected to the action of a current to perform some definite number of oscillations.

There are various ways of estimating the force of a current from the angle of declination, according as the electricity passes in a line or in a plane above or below the needle. If, as in Jacobi's Galvanometer-compass (*fig.* 188.), it is conveyed along a wire just under the needle, and in the direction of the magnetic meridian, Kämtz has determined that, *the force of the current acting on the needle is proportional to the product of the sine into the tangent of the angle of declination.*

Let c and C be the currents of two hydro-electric batteries, and α and α' the angles of declination they cause respectively in a galvanometer-compass, then

$$c : C = \sin.\ \alpha\ \tan.\ \alpha : \sin.\ \alpha'\ \tan.\ \alpha'.$$

To save the necessity of actual calculation, Pohl has constructed a table, which will be found below, for every angle from 1° to 90°, from which the proportional force of any current may be ascertained for any declination given in degrees.

TABLE XIV.

For determining the Intensity of Hydro-Electric Currents, from the Angle of Deflexion made by a Galvanometer-Compass. (Kastner's Archiv für die gesammte Naturl. III. S. 11. von Pohl.)

Deflexion of Needle.	Intensity of the Current.	Deflexion of Needle.	Intensity of the Current.	Deflexion of Needle.	Intensity of the Current.
1°	0·0001	31°	0·1016	61°	0·5179
2	0·0004	32	0·1087	62	0·5451
3	0·0009	33	0·1161	63	0·5740
4	0·0016	34	0·1238	64	0·6049
5	0·0025	35	0·1328	65	0·6380
6	0·0036	36	0·1402	66	0·6735
7	0·0049	37	0·1489	67	0·7119
8	0·0064	38	0·1579	68	0·7533
9	0·0081	39	0·1673	69	0·7983
10	0·0100	40	0·1770	70	0·8475
11	0·0122	41	0·1872	71	0·9014
12	0·0145	42	0·1978	72	0·9608
13	0·0170	43	0·2088	73	1·0268
14	0·0198	44	0·2202	74	1·1004
15	0·0228	45	0·2321	75	1·1833
16	0·0259	46	0·2445	76	1·2775
17	0·0293	47	0·2574	77	1·3854
18	0·0330	48	0·2709	78	1·5106
19	0·0368	49	0·2850	79	1·6577
20	0·0409	50	0·2997	80	1·8334
21	0·0452	51	0·3150	81	2·0471
22	0·0497	52	0·3313	82	2·3130
23	0·0544	53	0·3479	83	2·6536
24	0·0594	54	0·3655	84	3·1061
25	0·0647	55	0·3840	85	3·7378
26	0·0702	56	0·4035	86	4·6830
27	0·0759	57	0·4239	87	6·2551
28	0·0819	58	0·4455	88	9·6133
29	0·0882	59	0·4683	89	18·8034
30	0·0948	60	0·4924	90	infinite.

If, instead of conducting the current along a wire, it be conveyed under the needle by a strip of metal whose width is at least four times the length of the needle, the electricity flowing along this metal plate will act equally upon the needle in every position, for it must travel equally along the entire width of the conductor. In this case, *the force of the current is proportional to the tangent of the angle of the needle's declination.* Instruments constructed on this principle are called *Tangent Compasses,* and their application depends on Weber's law, which we have just briefly enunciated.

The force of those currents which deflect the needle only by means of some contrivance for multiplying their effects cannot be estimated by either of the laws given above, because, however carefully the instruments may be constructed, it would be very difficult to measure accurately the different distances of the needle from the respective turns of the multiplier, and the calculations involved in its use would be very complicated.

An extremely simple contrivance for measuring the intensity of a current by means of the angle of deflexion, consists in making the galvanometer itself to revolve in the plane of the horizon about the centre of the needle. When the needle has been deflected, turn the multiplier until, with regard to the needle, it has regained its original position, and the intensity of the current acting at right angles on the needle is equal to the horizontal force of terrestrial magnetism (§ 447.), which last force is measured by the sine of the angle through which the needle has been deflected from the magnetic meridian. But this angle is that through which the coils of the multiplier have been turned from their original position, and may be read off on a graduated scale made for this purpose. Pouillet's *Sine Compass* acts on this principle, that *the intensity of the current varies as the sine of the angle of torsion;* this instrument, when fitted up with a nonius, may be made to measure the angle of declination accurately to two minutes.

It is worthy of remark that, in all measurements from the angle of a needle's deflexion, if this does not exceed 20°, we may assume the *intensities of the currents to be nearly as the angular magnitudes squared.*

The method of measurement adopted by Ohm may also be used, the multiplier being used as a torsion balance and having its needle suspended by a fine wire, which is connected with the index of the torsion balance. When used, this index must be placed at zero, the needle too must be set at 0° in its scale; when the current acts on the needle it will deflect it a certain angle, and in so doing will impart a corresponding torsion to the wire. Now, instead of measuring the declination itself, you are to turn back the torsion index till the needle is restored to its original position. *The number of degrees which the index is moved back, is proportional to the intensity of the current.*

Lastly, the mode employed principally by Fechner in his admeasurements of observing the oscillations is equally applicable to the single galvanometer, and to such as are fitted up with a multiplier. Place the needle so that it shall stand in the direction of the earth's magnetic influence, and also in the direction in which the force is emitted from the electric conductor, so that in fact these two directions may coincide. To effect this, the single conducting wire of the compass, or the coil of wire of the multiplier, must intersect the magnetic meridian at right angles, *i.e.* it must be placed in such a position that the needle suffers no perceptible deflexion whilst acted on by the current (comp. § 512.). Now make the needle to oscillate, and by § 456., *the intensities of the currents are inversely as the squares of the times of the vibrations, or the number of units of time which are required to complete the same number of vibrations.* This method possesses the substantial advantage that it is applicable to both powerful and feeble currents, that it gives very certain and much more accurate measurements than can be obtained from the generality of instruments by reading off the angle of declination, and that the magnetic intensity of the current may at the same time be compared with the force of the earth's magnetism, by observing in like manner the time of the needle's oscillation when subjected only to the action of terrestrial magnetism; on the other hand, this mode of measurement renders it indispensable that the observer should have an accurate seconds' watch or pendulum, with which to compare the oscillations of the needle.

Suppose now that the needle when acted on by the current c, performs a certain number of vibrations in ten seconds, but that when subjected to the influence of another current C, it performs the same number in five seconds; then the intensities of these two currents will be

$$\begin{aligned} c : C &= \frac{1}{10^2} : \frac{1}{5^2} \\ &= \frac{1}{100} : \frac{1}{25} \\ &= 25 : 100 \\ &= 1 : 4 \end{aligned}$$

and further, if the same needle had required 20 seconds to make the same number of oscillations when acted on only by terrestrial magnetism M, then the forces would be to each other in the following proportion:

$$\begin{aligned} M : c : C &= \frac{1}{20^2} : \frac{1}{10^2} : \frac{1}{5^2} \\ &= 25 : 100 : 400 \\ \text{Or, as } & 1 : 4 : 16 \end{aligned}$$

i. e., if the force of the earth's magnetism is estimated as unity, that of the current *c* would be 4 times and that of C 16 times as great.

Magnetic measurements are also well suited to show with accuracy the influence which the magnitude of their excited surfaces exerts on the efficiency of hydro-electric batteries.

Fechner, who has performed a vast number of experiments to ascertain this point, has determined the following, viz. that the intensity of the current increases when the area of the excited surface is increased, but in a less ratio than it. The increase in the action of a battery is nearly proportional to the increase in the exciting surface, when the fluid employed is one that has but a low conducting power, such as water; whereas, when the fluids employed are good conductors, the increased efficiency of the battery is proportionally less. The increased force of the current, attained by increasing the excited surfaces, reaches a limit, which is arrived at the sooner the less the resistance to conduction offered by the fluid, as compared with the resistance offered by the solid conductor (*i. e.* by the connecting wire).

Pohl, whose attention has been carefully directed to these investigations, lays down the following law, that *the intensities of the currents of single hydro-electric batteries, in which both electromotors present equal surfaces to the exciting fluid, are, ceteris paribus, as the biquadrate roots of the areas of the surfaces in action.*

Suppose the metal surface in one single battery to be a, that of another $m\,a$, let c be the intensity of the lesser current; then that of the greater will be

$$C = c\sqrt[4]{m},$$

$$\therefore m = \left(\frac{C}{c}\right)^4$$

Hence it appears, that if a battery be given with a certain current, considered as unity, and we desire to construct another, the intensity of whose current shall be double that of the former; the batteries being similar, the exciting surface of the latter must be $2^4 = 16$ times greater than that of the former — I practically verified this law by comparing some Daniell's batteries, and found that to double the intensity of the current it was necessary to increase the copper surface sixteenfold. I used in each case the same wire to conduct the electricity, and I measured the intensities by the angles a galvanometer compass was deflected. I compared in like manner the intensities of a zinc and copper and of a zinc and platinum battery, the surfaces of the two metals being equal, and found that the current generated by the platinum battery was equal to what would have been produced by a copper one 16 times its size: this pretty nearly coincides with the results obtained by Jacobi, and given in § 505 of this work. For the zinc battery I used sulphuric acid diluted with 9 parts of water; for the copper, a concentrated solution of sulphate of copper; and for the platinum, nitric acid of 1·3 spec. grav., as the exciting fluids respectively. The intensities found thus were as 1 : 2, for the angles of the needle's deflexion were 34° and 46°, the corresponding intensities for which in Pohl's table are 0·1238 and 0·2445; their ratio is therefore as 1 : 1·94.—On comparing one of Hare's spiral batteries with one of Grove's, with respect to the effect of their current, the following result was obtained. The spiral battery had 372 square inches of effective copper surface; Faraday's fluid was used, and the needle of the galvanometer was deflected 36°, which, according to Pohl's table, corresponds with an intensity of 0·1402. A zinc and platinum battery, in which there were 100 square inches of the latter metal efficient, deflected the needle 46°, and consequently had an intensity of 0·2445. The same wire was used in each case to complete the circuit. According to the law given above, a platinum battery whose current should have the same intensity as that of the spiral battery would require a surface $m = \left(\frac{1402}{2445}\right)^4 = 0{\cdot}108$ times greater than it; *i. e.* $100 \times 0{\cdot}108 = 10\frac{4}{5}$ square inches. Now when only 10$\frac{4}{5}$ square inches of the zinc and platinum battery were set in action, the compass gave a declination of precisely 36°, consequently these 10$\frac{4}{5}$ inches of platinum generated a current whose intensity was exactly equal to that produced by 372 inches of copper in Hare's spiral battery. To give to both batteries an equal intensity of current, the copper surface of the latter would require to be $372 : 10{\cdot}8 = 344$ times greater than the platinum surface of Grove's battery.

§ 523.

At the conclusion of this important branch of the science of electricity, it is necessary that the reader should be made acquainted with the opinions of natural philosophers with regard to the primitive causes which generate galvanic or voltaic electricity. It is remarkable that the views of scientific men on this subject do not accord, notwithstanding the zealous investigations which have been made so lately into the sources of electricity, investigations too which have brought to light so much that is both new and important. The majority of the scientific world are the adherents of one or other of two theories; the older of which, known as the *theory of contact*, is based on the principle laid down by Volta; the other, first propounded by Wollaston, is called the *chemical theory*.

The contact theory, which is held by most of the German philosophers, especially by Ohm, Fechner, Pfaff, Henrici, Poggendorf, Berzelius, Jacobi, and Martens, assumes that when two dissimilar bodies are brought into actual or proximate contact an energy is developed to which has been given the name of *electromotive force*, but whose nature is still unknown. This electromotive force effects the decomposition of the neutral electricities of the two touching bodies, so that a definite portion of the + electricity accumulates in one of them, and a corresponding portion of — electricity in the other; but it instantly opposes the reunion of these ± electricities, and thus occasions the constant difference of tension between bodies in contact. To account for the influence of the chemical process on voltaic phenomena, Fechner assumes that, between the atoms of two bodies which combine chemically with each other, a process obtains similar to that which arises when two heterogeneous substances are in contact. The atoms charged with antagonist electricities are held together by their mutual attraction; and this constitutes what is generally known as *chemical affinity* (§ 58).

According to the *chemical theory*, which has recently been greatly extended, especially by Faraday, De la Rive, Becquerel and Schönbein, galvanic electricity is attributed to a chemical action, and its most zealous advocate De la Rive speaks in the following terms: so soon as a body comes into a gaseous or fluid medium and a tendency arises between the two bodies to combine chemically, a disturbance ensues in the electrical equilibrium, and on this condition of chemical action being fulfilled, the elements of the solid combine with the oppositely electrified elements of the fluid. As a general rule, the body, *ex. gr.* the metal, which is dissolved in the process of combining, is positively electrified, and the fluid which performs the part of the agent is negatively electrified: but, as in such processes a separation of the atoms takes place, that liberates the electricity which was before held in a latent state, and which is always opposite to that which disposes the atoms to form a new combination, the result of both processes is dependent on the difference of the two influences. The intensity of the electric action thus set at work is regulated by the difference just mentioned and also by the hindrances which oppose themselves to the re-union of the electricities that are set free. If two heterogeneous metals are brought into contact in a medium that acts with unequal energy upon them, it will render them both electrical, that for which it has the stronger affinity being positive, and the other negative. Join several such pairs so as to form a compound hydro-electric battery, and all the rest will perform the functions of a conductor of the free electricity to each pair; the ± electricities thus meeting together in the metal, neutralize each other with respect to their quantities, the + electricity will therefore accumulate on one side and the − electricity on the other.

The advocates of each theory have been and are still employed in bringing forward proofs to establish the correctness of the views they have respectively taken, without either party being at present able to claim an undisputed victory. To these labours, however, we are in a great measure indebted for the advances that have in modern times been made in this department of science. The thorough-going supporters of the chemical theory positively deny that electricity is ever excited by contact alone, and they even go so far as to say hypothetically, that the pure metals are susceptible of oxidation. Fechner has, however, compelled them to admit that Volta's fundamental experiments are a fact too well established for us to doubt any longer whether electricity can be generated by contact only, and there are even cases of hydro electric combinations in which electrical action obtains, agreeably to the assumptions of the contact theory, without any chemical action whatever of the fluids on the electromotors (1): nay, frequently the contact of the metals is the cause that this action, originally a purely chemical one, is suspended and an opposite one commences (2). Many partisans of Volta's theory are decidedly of opinion, that chemical action is never the primitive cause of electrical excitement, although they do not call in question the possibility of chemical influences being frequently the immediate, but not the original, cause by which electricity is generated (3): some who hold this theory even concede that chemical action may increase the intensity of the electrical process, when its excitation coincides with that of contact. After all, the main difficulty will be to determine what share chemical influence really has in exciting electrical action, because without contact scarcely any chemical change can transpire, and also because the effect produced must depend on so many secondary circumstances, such as the degree of concentration of the solutions, the temperature of the fluid, &c.

1.) Pfaff adduces the following *experimentum crucis* to show, that without any chemical action whatever by the fluids on the electromotors immersed in them, a powerful electrical excitement is generated solely by the contact of the latter.

First Expt. Take a zinc and platinum battery, and use a neutral solution of sulphate of zinc as the fluid which is to act on the zinc, and for the platinum, as usual, nitric acid; then neither of these fluids will exert any chemical influence on the metals immersed in them, according to the laws of chemical affinity, and yet a current of electricity will be generated as powerful or nearly as powerful on connecting the wires as if sulphuric acid had been used with the zinc.

2.) Berzelius gives the following as a strong proof that the excitation of electricity by the contact of heterogeneous bodies is altogether independent of the chemical influences acting on them, and that the excitation of electricity regulates the chemical action, nay, even reverses it sometimes.

Second Expt.

Fig. 196.

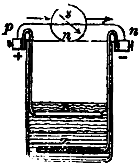

Fig. 196. represents a simple battery of two metals and two liquids; Z is an amalgamated zinc plate near the bottom of the cylindrical glass vessel, and C is a copper-plate of equal size, parallel to it. A bent strip of metal goes from both and being bent over the rim of the glass supports the two plates and performs the office of a conductor to them; its ends *n* and *p* are provided with binding screws, and the whole of the strip is coated with a varnish by which it is protected against any chemical action. A perfectly saturated solution of sulphate of zinc is poured on the bottom of the glass till it reaches half way between the plates of zinc and copper; on the top of this pour some common nitric acid through a fine glass funnel whose tube is slightly curved at the end, so that the acid may lie on the much heavier solution of zinc without forming a mixture with it; continue to add acid till it stands about half an inch above the copper-plate.

Until the circuit is completed by connecting the wires, the chemical forces alone are in operation, and in accordance with the laws of affinity, the copper is rapidly dissolved by the acid, whereas on the zinc no action takes place or can take place. Now if the chemical theory were correct in assuming that the oxydation of one of the metals controlled the electrical relations of the battery, then the copper, as being the metal which is chemically affected, must needs be positively electrified and the zinc negatively. But on completing the circuit the solution of the copper ceases instantly, the green tint disappears gradually from the solution, and the reduction of the copper held in solution begins on the copper-plate, whilst a cloudy appearance rises about the zinc caused by the formation of the oxide of zinc, and a galvanometer compass forming a part of the electric circuit would shew that the current had taken the direction which accords with the principles of the contact theory.

3.) To prove the generation of electric forces by means of a chemical combination, Becquerel adduces the combination of an acid with an alkali.

Third Expt. Pour a little nitric acid into a platinum saucer, which is connected with one wire of a galvanometer: connect the other wire with a piece of platinum wire whose free end is bent into a hook, about which twist some asbestos or cotton, saturated with a solution of potash or soda. At the moment when this alkali is dipped in the acid contained in the platinum saucer, the needle of the galvanometer shows the existence of a current passing from the alkali to the acid.

Explaining this on the principles of the chemical theory, the current is generated by the chemical action of the fluids one upon the other; by the contact theory it would be attributed to the electromotive action of the different fluids on the platinum, or the whole combination would be regarded as a battery of one homogeneous metal in two heterogeneous fluids. (§ 505.)

It is by no means improbable that neither of the theories, pushed to an extreme, fully coincides with the truth; and some philosophers, amongst whom are to be reckoned Jacobi, Buff, Baumgartner, Von Ettinghausen, and Pohl have constructed a theory which holds a middle course between the two we have already explained. These views merit a place in this part of our work, as in them what is favourable to each of the other hypotheses is fused together in such sort that the various phenomena are more satisfactorily accounted for than by either of the original theories.

It has long been held that those forces which lie at the basis of adhesion, and those which cause chemical affinity, are not essentially different: some philosophers have even attempted to estimate the degrees of affinity by the amount of adhesion. It is therefore by no means unscientific to regard chemical attraction as merely a more powerful adhesive force. Prechtl has indeed tried to prove the connexion between the adhesion of metals and their electrical difference, *i. e.* their relative position with respect to tension (§ 502.); Becquerel has shown that electricity is generated by capillary attraction, which is known to depend on adhesion and cohesion. Again, we know from Girard's experiments, as well as from the theory of capillary tubes, that adhesion causes a variation in the density of fluids where they are bounded by solids. Resting, then, on these facts, we believe that, *when electricity is generated in any voltaic arrangement, it results from a molecular change brought about in the touching bodies by the adhesive force which subsists between them.* This change is sometimes merely in the density of the touching bodies, it is often confined to the strata contiguous to their points of contact, but with a force of considerable intensity, and under favourable circumstances, it extends to the chemical nature of the bodies. This theory possesses the advantage that no new power need be assumed to exist (whereas the contact theory requires us to allow the existence of the electromotive force); and it also accounts for the production of electricity apart from any chemical action. It has this in common with the chemical hypothesis; that it deduces the phenomena of the single battery from the molecular forces; that it considers the fluid not merely as a conductor of the electricity, but as engaged in its production, and that the elements of the battery, by the physical changes they undergo, are the actual sources of the electricity; that their contact renders this change possible; that it therefore is the occasion, and not the generating cause by which the electricity is produced. In these points it approximates more nearly to the chemical than to the contact theory, which supposes that electricity may be developed without any further change in the bodies: indeed the chemical hypothesis is merely a special case of the molecular. The simultaneous commencement of chemical action with the development of electricity, and the circumstance that the chemical intensity of a simple voltaic arrangement increases and decreases as the chemical action on the fluid conductor and on the elements of the battery is greater or less, fully accords with the statements of this theory. It follows, hence, that the electrical and molecular force are one and the same, and that the latter appears as electricity whenever it passes from one mode of operation into the other, as, *ex. gr.*, when it ceases to hold together the elements of the water, and so oxydizes the zinc. Schönbein's most recent hypothesis of chemical tendencies does not differ essentially from the views just explained.

IV. ELECTRICAL PHENOMENA RESULTING FROM THE CHEMICAL ACTION THAT ATTENDS THE CHANGE IN THE AGGREGATE FORM OF BODIES; THOSE WHICH RESULT FROM THEIR SEPARATION BY MECHANICAL MEANS; AND THOSE WHICH ARE CAUSED BY THE COMPRESSION OF BODIES.

§ 524.

Next in order to those electrical phenomena which are produced by friction, and those which are generated by contact, we must place such as attend the chemical action of bodies one on another, the change in their aggregate forms, the destruction of their cohesion by mechanically separating their particles, and by pressure. In all the instances just specified, a change takes place in the molecular condition of the bodies, partly in the interior of their masses, partly at their touching surfaces, and according to the opinions of some philosophers (see § 500. and 528.), this change may in these instances also be regarded as the universal cause by which electrical equilibrium is disturbed.

The condition of electrical neutrality is upset in chemical combinations and decompositions of many bodies, as may be proved indisputably by connecting the bodies, thus combining or decomposing, with the wires of a galvanometer, or with the conductor of a sensitive electrometer. Now whether the current indicated by the galvanometer, or the electrical tension marked by the electrometer, be owing, according to the contact theory, to the bodies touching each other, or, according to the chemical theory, to the chemical action of the substances on each other, the adherents of both theories will allow that a disturbance of the electrical equilibrium, as shown by the galvanometer or electrometer, actually exists; now, as by the electro-chemical system (§ 516.), every chemical combination depends on the union of electrical opposites, the state of electrical equilibrium will necessarily be destroyed both in chemical combinations and decompositions. The following experiments are given as illustrations of the excitement of electricity attending both these kinds of chemical operations: —

First Expt.. Electrical excitement with chemical combinations. — Nobili gives the following experiment to prove that electrical excitement is the result of chemical combination; Fechner repeated the experiment with some variation: —

Fill two small glasses, A and B, with a solution of nitrate of potassium into which conduct the wires of a galvanometer whose ends are armed with plates of platinum. A third glass, C, containing dilute nitric acid, is then placed near the other two, with which it is connected by means of two threads of asbestos or cotton, dipped in the dilute nitric acid. Now twist one of these conductors about a small piece of caustic potash before using it to establish the connection of the battery, and a chemical action will immediately commence of these two substances, and at the same time a deflexion of the galvanometer needle, which shows that the current passes from the potash to the nitric acid. Similar deflexions ensue with other chemical combinations of the same kind, as well as with those in which the substances that have an affinity for each other do not acquire a conducting power until they have been fused or melted.

In the arrangement just described, it is to be noticed that the platinum plates connected with the galvanometer are immersed in the same fluid which is contained in the glasses A and B, and that consequently the electric current is not generated by the contact of the metal with heterogeneous fluids, but the electrical equilibrium is disturbed in the glass

C at the very instant when the caustic potash comes in contact with the nitric acid.

A much more powerful current is obtained by leaving out the middle glass C, pouring nitric acid into A and a solution of caustic potash into B: the homogeneous platinum plates are then to be plunged in the heterogeneous fluids, and A and B are to be connected in the same way as before. By this arrangement we obtain a Becquerel's battery (§ 505. 2.) A current is generated by the contact of the platinum with these two dissimilar fluids, similar to that which was produced by the chemical action of the caustic potash with the nitric acid. From the difference between the intensities of the currents, we see at once what share is to be attributed to each of the exciting causes in the case where their operations are combined.

Second Expt. Immerse simultaneously two homogeneous strips of platinum, connected with the wires of a galvanometer, in a glass containing nitric acid. The platinum plates are then in contact with the same fluid, and that one which exerts no chemical influence on them; the needle of the galvanometer will therefore be at rest. Now let fall one drop of hydrochloric acid on one of the platinum plates, and instantly the needle will be deflected, showing the passage of an electric current from one plate to the other. The nitro-muriatic acid formed by the drop of muriatic acid acts chemically on the platinum in contact with it. This instance is, however, one of those in which it is difficult to determine what share chemical action really has in eliciting the electric current. The adherents of the chemical theory consider the chemical action; while the partizans of the other hypothesis regard the contact of the homogeneous metal with the heterogeneous fluids as the sole cause by which the current is excited. Probably the fact is, that it is owing to the two agencies combined.

Third Expt. Electricity produced by Combustion. — According to Pouillet's experiments, when charcoal is burned it is rendered negative, and the carbonic acid which is formed is positive. He placed a small cylindrical piece of good conducting charcoal, having a very smooth bottom, on a plate of brass, which was connected with the condenser of an electrometer, and then ignited its upper end. The combustion was supported and accelerated by blasts of common air, or, still better, by a supply of oxygen. When the lower plate of the condenser was connected with the ground, the instrument appeared in a few seconds to become charged with — electricity. When the charcoal was set on a metal plate connected with the ground, and, during the process of combustion, held so beneath the brass plate of the condenser that the carbonic acid which was generated was accumulated on it, the condenser was charged with positive electricity. Dellmann also noticed the liberation of — electricity attending the combustion of charcoal, and Pfaff confirms it, but denies that the least trace of + electricity is to be found in the carbonic acid which is given off. Several philosophers have asserted that analogous traces of the liberation of electricity attend the combustion of some, but not of all, combustible bodies.

Fourth Expt. Electricity produced by Chemical Decomposition. — The experiments of Dr. Böttger may be adduced as examples: — Connect a platinum cup with the condenser or with the conductor of a delicate electrometer by means of a wire terminating in a ring. On this ring lay the cup, put in it a few grains of citrate or oxalate of silver, and apply the heat of a spirit-lamp until the salt is dissolved. Remove the lamp, and the electrometer shows — electricity to have been liberated; and in the platinum cup some very fine and minute particles of metallic silver will be found.

Fifth Expt. Lay a piece of blotting paper moistened with water on a metal plate connected with the condenser, and on it place a few crystals of nitrate of copper wrapped up in tinfoil. Pierce a few holes in the tinfoil with a pin. Moisten the whole with a little weak spirits of wine, and the salt will soon begin to decompose; and at the moment when sparks become visible, and nitrous vapour rises, the condenser is charged with — electricity.

Sixth Expt. On the conducting plate of any sensitive electroscope (*ex. gr.*, either a Becquerel's, *fig.* 157., or an Oersted's, *fig.* 156.), lay a zinc cup, and pour into it dilute muriatic or sulphuric acid, and the electroscope will show, after the hydrogen has been given off and a chemical solution of the metal has been formed, that — electricity has been liberated. A similar phenomenon is observable if, as in the fourth experiment, clean iron filings are placed in the platinum cup, and either muriatic or sulphuric acid poured on them.

§ 525.

Electrical phenomena have been seen to attend a change in the aggregate form of many bodies, especially in the solidification of such as are in a state of fusion, and in the freezing of water. The sparks that become visible during the crystallization of certain salts, and the attendant electroscopic effects, seem rather to result from a separation taking place among the crystals after their formation, than to be a consequence of crystallization itself.

> *First Expt.* Melt some sulphur in a glass, and cool it on any good conductor; on taking it out of the glass it will be negatively electrical, and the glass will be positive. Perform the same experiment in a metal cup: the latter will be negatively electrified, and the sulphur positively. Similar phenomena may be observed in the solidifying of chocolate.
>
> It cannot be positively asserted that the electrical phenomena just noticed are absolutely consequences of the change of aggregation in the mass of the body. Some philosophers are of opinion that they are properly owing to the friction which is generated when the solid bodies are separated from the vessels containing them. If this supposition is correct, these phenomena come rather in that category of which we shall have to speak in the next section.
>
> *Second Expt.* Water frozen quickly at a very low temperature (22° below zero, Fahr.) in a glass coated outside like a Leyden jar, according to Grotthuss, is positively electrical; if melted rapidly at a high temperature it shows — electricity.

Undoubted proofs are still wanting to show whether electricity is liberated by the change of liquids into steam or by the condensation of the latter. Pouillet is persuaded that from numerous experiments, he has found the escape of steam from alkaline water accompanied with positive, and that from acidulated water with negative, electricity; Pfaff, who repeated the experiments, doubts the fact. As the results, as well as those which attend the combustion of bodies, are of considerable importance on account of the conclusions that have been drawn from them respecting the electrical phenomena that arise in the atmosphere, and especially since some doubt is felt as to their correctness, it is much to be wished that the same experiments should be repeated, and careful reference be made to all circumstances affecting the results.

That a considerable quantity of electricity is liberated when high-pressure steam escapes into the atmosphere was discovered accidentally in 1841, when it was first noticed in the boiler of a locomotive engine. Armstrong, who rigorously investigated the phenomenon, found no trace of sensible electricity in the steam contained in the boiler; and that none was developed till the steam reached the open air, when it was invariably positive; that the production of electricity was proportional to the amount of steam generated, and that its intensity increased with the tension of the steam; lastly, that not only were sparks emitted by it, but it gave shocks like those obtained from a Leyden jar. Pfaff performed the same experiments with a Papin's digester, and confirmed in general the correctness of Armstrong's inferences; he obtained precisely similar results when he used distilled, alkaline, and acidulated water. His opinion is that the electricity is generated by the pressure of the steam on the water; he therefore considers that these phenomena may properly be ranged under the head of electrical phenomena produced by pressure; Armstrong, on the contrary, thought at first that this electricity arose from the condensation of the steam, but he has since given it as his opinion that the electricity is generated when the steam is exposed to friction: he does not, however, believe that this friction is the exclusive cause of its production. His investigations may involve important consequences which have not yet been perceived, for in high-pressure steam we have so remarkably fertile a source of electricity, as greatly exceeds the best electrical machines.

A short description of Armstrong's *Hydro-Electric Machine* may not be out of place here. It consists of a boiler of wrought iron of cylindrical form 3½ ft. long and 1½ ft. in diameter; its ends are rounded off into hemispheres, and with its frame and grate for the firing, it is insulated by means of glass legs. When the steam is allowed to escape through certain cocks constructed for that purpose, the pressure being 70 lb. to the square inch, an effect is obtained 7 times greater than from a good electrical machine with a plate 3 ft. in diameter; the comparison was made in the following manner. A Lane's jar (§ 487. *fig.* 162.) with 198 sq. in. of coated surface, was used to measure the electricity generated by both the machines. When the balls were held ¼ an inch apart, and the plate was turned round 70 times in a minute, 29 discharges were obtained from this electrometer; on connecting it with the insulated boiler 220 discharges were obtained in the minute. Armstrong considered that each single ray of steam as it issued from the cock into the air, gave out as much electricity as a good electrical machine of ordinary size; and as a boiler capable of generating steam equal to that of a locomotive engine could discharge 100 such rays, we may form some idea of the prodigious development of electricity that may be effected by means of steam.

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* NOTE. — The subject has been investigated by Faraday, who thus expresses the conclusion at which he arrived: — "The cause of the evolution of electricity by the liberation of confined steam is not evaporation; and further, being, I believe, friction, it has no effect in producing, and is not connected with the general electricity of the atmosphere: also, that as far as I have been able to proceed, pure gases, *i. e.* gases not mingled with solid or liquid particles, do not excite electricity by friction against solid or liquid substances."

§ 526.

Electrical phenomena have been noticed in many bodies, especially in those of crystalline form, when a sudden disruption of their internal structure takes place. When by mechanical or other means their cohesion is overcome, sparks are seen, and the divided portions are in a state of opposite electrical tension.

The following experiments may serve as illustrations:

First Expt. Becquerel observed that when a small cleft was made in a lamina of mica, and a stick of sealing-wax was fastened to the portions of the crystal thus prepared for splitting, on tearing them asunder a luminous appearance was visible in the dark, and each of the fragments after rupture was oppositely electrified. The like obtains with other crystallized minerals if treated in the same manner. We may mention gypsum, calcareous spar, &c.; the same phenomenon may be noticed in tearing a common playing-card.

Second Expt. Dr. R. Böttger mentions the following electrical phenomena as observed by him in a salt crystallized by fusion. Connect a platinum dish or a small crucible by means of a bent wire, with the conductor of a sensitive electroscope. In this metal vessel place some crystals of sulphate of copper and potash, which are to be heated by applying a spirit lamp under the dish until the crystals have parted with their water of crystallization, and are reduced to a perfectly liquid state. When the whole is in this state of fusion remove the lamp, and within a few seconds the entire mass will crystallize, but without any trace of free electricity; so soon, however, as the mass has acquired a solid crystalline structure, it begins to contract and gradually to rend asunder, this process being attended by an audible crackling noise; the electroscope distinctly shows + electricity to be liberated every time that the contraction of the mass produces a rupture in the individual particles. In proportion as the mass becomes gradually reduced to a pulverized condition, the electrical phenomena disappear; the experiment may however be repeated at pleasure by fusing the salt in the manner described already. Dr. Böttger considers this as a convincing proof that electricity and light are evolved, not so much at the moment when the crystals are formed, but rather when a crystal already formed touches or destroys another; he is also of opinion that the bright sparks which, according to Rose's observations, are to be seen in gradually cooling a solution of white arsenic, are derived from a like source.

Lastly, we must reckon under the same class all those electrical phenomena which accompany the pressure and subsequent disruption of two bodies. We may conjecture that in these also the disruption effected by the previous pressure produces the same consequences as the suspension of cohesion in the preceding experiments; the separated bodies invariably show themselves as differently electrified, this difference being greater the greater the adhesive force which has been overcome. The quantity o electricity set free depends also on the nature of the bodies themselves, on the degree of pressure to which they are subjected, on their conducting power, and on the temperature and structure of their surfaces.

> Becquerel has proved by a variety of experiments that any body whatever may be rendered electrical by pressure. Discs of the substances to be tested were prepared, and then fixed on insulating stems of glass or sealing-wax. These plates were then pressed together, and sometimes they were pressed against other bodies; after the continuance of the pressure for some time they were suddenly separated. The electricity thus evolved may be observed on a delicate electroscope. Becquerel performed these experiments with cork, elder-pith, caoutchouc, orange peel, starch, Iceland spar, gypsum, fluor spar, with several of the metals, and even with condensed fluids.

V. ELECTRICITY GENERATED BY HEAT, LIGHT, AND MAGNETISM.

§ 527.

We have already seen that conditions may frequently arise in which heat exerts an immediate influence on electrical action, and sometimes it is itself excited by that force. Heat is, however, one of those causes which immediately disturb in many bodies their condition of electrical equilibrium; especially when the temperature of a part of their mass is either raised or lowered. The phenomena arising from these causes are generally classed together as belonging to *Thermo-electricity.*

There are two electrical states, into either of which bodies may be brought by the operation of heat upon them; that is to say, there may be excited in them either a state of electro-polar tension, or a current of electricity may be generated. In many bad conductors, and even in good ones if insulated, the ± electricities elicited by heat are held asunder in the bodies for a length of time in such a manner that one part will be in a state of negative and the other of positive tension, very similar to electrical induction. In good conductors, especially in the metals, this statical electrical condition is converted into the dynamical, *i.e.* currents are generated whose direction varies according to the nature of the metal or conductor itself, and the mode in which it is combined with others: to distinguish these from other electrical currents they are called *thermo-electric.*

The first-named phenomenon has been long known, but it stood as an isolated fact, which contributed but little to the advancement of this branch of science. It was far otherwise, however, with the electro-dynamic effects of heat that have been discovered of late years. This inference has been drawn from them: that heat is a far more general cause of the disturbance of electrical equilibrium than had hitherto been imagined. They have indeed led the way to several interesting discoveries, and to extremely important conclusions as to heat being a principal agent in generating the planetary electricity of our earth.

§ 528.

Thermo-electric polar tension is displayed principally in crystallized substances, especially in such as belong to the mineral kingdom; hence it has sometimes been called *crystal electricity,* and the crystals which display this property are termed *thermo-electric* crystals: they are for the most part such as are not symmetrically formed at their opposite ends. The greatest number of experiments has been performed with *tourmaline,* which is the first crystal whose thermo-electrical properties were discovered. The most important results from these observations are the following:

1.) At a temperature lower than 86° tourmaline is destitute of electrical properties.

2.) When the temperature is raised, it becomes electrical, in the same proportion as its temperature is elevated; one half of it being positively, and the other half negatively electrified. In perfectly-formed crystals the pointed end with three faces is positive, and that with six sides is negative.

3.) When the temperature remains stationary, the electric tension disappears.

4.) When the temperature is lowered, the crystal again becomes electrical, but the end which before was positive becomes negative, and vice versâ.

A crystal of tourmaline may be electrified thus: —

First Expt. Hold the crystal for a few minutes in boiling water; grasp it in the middle with a pair of pliers, take it out of the water, and one of its ends will appear positively electrified, and the other negatively, if tested by a sensitive electroscope.

This property in tourmaline was known to Æpinus; it was subsequently found that it belonged to other and even to artificial crystals. The philosophers who have done the most to extend this department of science are, Brewster, Haüy, Ermann, Becquerel, Forbes, Hankel, P. Riess, and G. Rose. In all bodies of this class the tension is of very low intensity; so that up to the present time no use has been made of this source of electricity.

In good conductors a state of thermo-electrical tension is induced only by insulating them, and applying a strong heat to one end, which becomes positively electrified while the opposite extremity is negatively electrified.

Second Expt. Connect a platinum wire with the plate of a condensing electroscope, and let the free end terminate in a helix. Now raise the spiral to a red heat, hold the stand of the condenser in your hand, and form a conductor of moistened paper to the spiral; the latter will be charged with positive electricity, and the plate of the condenser with negative.

§ 529.

Heat, or cool, one end of any good conductor, as a wire or strip of metal; on hinging together its two ends, which stand at unequal temperatures, a *thermo-electric current* will be generated. The same result will follow at any part of an electric circuit where the mass of the body is at all modified, as, for instance, where a difference in the thickness or in the density of the substance causes a variation in the temperature. In both cases an opportunity is offered by the local influence of the heat for the ± electricities, which had been held asunder to re-unite in the path presented to them by the conductor. Had no such variation existed in the interior of the conductor, that is to say, had it been perfectly homogeneous throughout, as in a wire of exactly equal dimensions from end to end, then no electric current would have been generated From this and similar circumstances Becquerel thinks we are warranted in inferring that a change in temperature is not the sole requisite for the production of thermo-electric currents, but that other causes must be in operation by which the distribution of heat is hindered from being uniform, so that it moves more rapidly on one side than on the other of the hot or cold spot.

The intensity of the current varies according to the nature of the conductor used; as a general rule, it is greater the greater the difference in the temperature, and as this diminishes again the intensity becomes less.

With regard to the degree in which the metals become electrical through inequality in their temperature, Yelin gives the following list, in which he places first that which is most powerfully excited, and the last that which is least so: bismuth, antimony, zinc, silver, platinum, copper, brass, gold, tin, lead: Emmett and Nobili have arranged the metals in two groups, according to the direction the current takes; in the one class placing those in which the positive current is propagated in the same direction as the heat, in other words, in which it goes from the hot to the cold part of the metal; in the other group those in which the currents of heat and positive electricity run in opposite directions. Emmett places platinum, gold, silver, copper, and nickel in the first, and tin, lead, zinc, iron, brass, arsenic, antimony, and bismuth in the second. Nobili reckons bismuth, platinum, gold, silver, tin, brass, lead, and copper to belong to the first class, and zinc, antimony, and iron to the second. From these two lists it is readily seen that the negative metals which are not easily oxydized by heat give out + electricity, and the positive metals which soon oxydize give out – electricity. Nobili says that if two dry cylinders of clay be connected by means of a wire, and the end of one be very much heated, and then placed in contact with that of the other, a current of electricity will immediately proceed from the hot to the cold cylinder.

To prove the production and existence of thermo-electric currents, it is necessary to make use of a galvanometer (§ 512.). Since, however, they possess but a small intensity, the resistance to conduction in the instrument itself should not be considerable. This is effected by making but few coils, and employing pretty stout copper wire, about $\frac{1}{30}$th of an inch in thickness; or Fechner recommends a strip of copper instead of the coils of wire, and an astatic needle having the freest possible motion, such as is used in Nobili's galvanometer. (§ 512., *fig.* 190.)

Fig. 197.

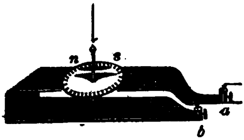


Fig. 197. represents a strip of copper thus substituted for the usual coils of wire, the width of the metal being equal to the length of the needle. The ends are shown in the diagram to taper off, and are bent so that they can be brought in a horizontal position near to each other; they are furnished with binding-screws, *a* and *b*, to secure the ends of the conductor in which it is desired to generate a thermo-electric current. In the upper plate is a slit through which the lower needle, *n s*, suspended by a thread, can be let between the two plates; as in other galvanometers, the upper needle traverses above a graduated circle; in other respects the use of this instrument resembles that of Nobili's double galvanometer, of which a representation was given in *fig.* 190.

The generation of such currents may be proved by the following experiments:—

First Expt. Fasten two wires of the same metal with the binding-screws of a thermo-galvanometer, and heat the free end of one wire by means of a spirit lamp: then bring the cool end of the other into contact with it, and the instantaneous deflexion of the needle will indicate the direction and intensity of the current. Increase the difference in the temperatures, and there will ensue a greater deflexion, which will gradually diminish as the heat becomes equalized at the touching points. To obtain a powerful current, it is as well if the wire terminate at the heated end in a plate.

Second Expt. Procure a piece of platinum wire, about $\frac{1}{60}$th of an inch in thickness, tie a knot in the middle, or twist the middle part into a helix, connect the end of this wire with the conductors of a thermo-galvanometer, heat the middle part of the wire by applying a spirit lamp under it; the needle will soon be deflected, thus showing that an electric current has been elicited, which runs from the heated part of the wire towards its extremities.

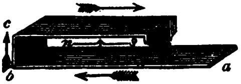
Third Expt. Thermo-electric currents may be produced even in such metals as are of uniform thickness throughout their extent, and which as far as concerns their chemical structure are perfectly homogeneous, provided that in the interior of their masses any molecular difference exists, or that such difference is brought about artificially; this frequently happens in the crystalline metals, bismuth and antimony, when they solidify unequally; it may also be artificially induced in iron by raising it to a white heat, and in steel by partially hardening it.

Make a piece of iron wire red hot at any particular spot, allow it to cool and again heat it near the same place, you will find it has become thermo-electrical; this you may see by connecting it with a thermo-galvanometer; this is owing to a change having been made in its internal structure, by which the uniform conduction of the caloric in both directions has been interfered with.

So also, if one side of a steel horse-shoe be hardened and the other be left soft, on applying heat to the curved part the metal will be found to be electrical.

Fourth Expt. The thermo-electric current generated in a homogeneous metal may be detected without the aid of a galvanometer, by means of a very simple apparatus invented by Yelin. It consists of a strip of copper bent into the form *a b c d e*, *fig.* 198., and riveted at *e*. In the middle of the two plates is a needle of low magnetic power, balanced on a point. Now heat the free end of the strip *a* by the flame of a spirit lamp, and the conduction of the heat will take place in the direction from *a* to *b*, *c*, *d*, and *e*; and the current will be generated in the same direction as is indicated by the arrows; the needle will hereby be deflected to the east. Wrap a roll of cotton, or a hank of thread, round the free end; drop on it a little sulphuric æther, and the cold produced by its evaporation will deflect the needle westward, proving the existence, this time, of an opposite current to the former. The effect is rendered still more powerful by wrapping the bandage about *c*, cooling it as before, and, at the same time, heating the end *a*.

Fig. 198.



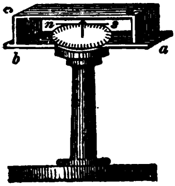
§ 530.

Much more powerful thermo-electric currents are produced in circuits composed of heterogeneous metals, by either heating or cooling the places where two dissimilar metals are soldered together. Combinations of this kind form *single thermo-electric batteries*, which, without a galvanometer, show the existence of the current by means of a magnetic needle brought within the circuit. These are the thermo-electric currents that were first observed, having been discovered by Seebeck in 1821.

The direction taken by a current in one of these batteries depends partly on the nature of the metals of which it is composed, partly in the difference in the transmission of the heat; *i e.* when the points of junction of the two metals are cooled the direction of the current is exactly opposite to what it is when they are heated. By variously combining the metals it was soon found that, with regard to the excitation of electricity by heat, a similar relation obtained as when it was excited by contact; and that they might be arranged in a *thermo-electrical order of tension*, according to their different electromotive efficiency, as *thermo-electromotors*. We have already given a similar series for contact or voltaic electricity (§ 502.). Seebeck's list is as follows:—bismuth, nickel, cobalt, palladium, platinum, uranium, copper, manganese, titanium, brass, gold, mercury, lead, tin, chromium, molybdenum, rhodium, iridium, silver, zinc, tungsten, cadmium, steel, iron, arsenic, tellurium, antimony. Of this series bismuth is the most electro-negative member, and antimony the most electro-positive. Thus, as in the series with regard to voltaic tension, each metal combined with any of the succeeding will, on being heated, become negatively electrical; if joined with any that precede it, it will become positively electrical: these circumstances are reversed if its temperature be lowered. The difference of temperatures being the same, the intensity of the current is greater the farther the metals are asunder in this series. Bismuth and antimony, as the two extremes, form the most powerful thermo-electric batteries; so sensitive, that by touching them at the point of juncture with the naked hand the needle is deflected, the temperature of the metals being but little above the freezing point. Brass, which stands pretty near the middle of the list, if combined with bismuth or antimony, constitutes a thermo-battery of mean power. When combined with bismuth, brass is the electro-positive element, and with antimony it is the electro-negative. Further, it has been ascertained that, within tolerably remote limits, the intensity of many batteries is proportional to the difference in the temperature of their elements, while with others this proportion is confined within an extremely narrow range, or even has no existence whatever. Another coincidence which obtains between the thermo-electric and the voltaic series consists in this, that, in such batteries as are composed of more than two heterogeneous metals, the intensity of the current is the same as would have been obtained by combining only its most negative and most positive members. It must be further remarked, that this relative position of the metals in the series holds good only when they are chemically pure, and that when alloyed at all their position is thereby materially affected. Hence it has been presumed that we are furnished with a test of the purity of the metals.

Seebeck and Cumming have also noticed that combinations of the earths and other conductors of electricity form thermo-electric batteries, a fact which is especially of importance on account of the inference drawn from it as to the existence of similar currents in the earth's crust: this subject will be more fully treated of in § 533.

Fig. 199.



A very convenient mode of constructing these simple thermo-electric batteries is represented in *fig.* 199. *a b* is a bar of bismuth or antimony, about 4 or 5 inches long, from $\frac{1}{2}$ to $\frac{3}{4}$ of an inch wide, and about 1 or 2 lines in thickness. To it is soldered a strip of copper or brass, of equal width but rather shorter, bent at right angles at *c* and *d* in such a manner that the distance between the parallel metal plates is about an inch. As has been remarked above, the most powerful simple battery is obtained by combining antimony and bismuth in this manner. In the middle of the lower plate is an upright piece of wire, finely pointed, and carrying a sensitive needle, *n s*, which has a graduated circle immediately beneath, on which the angle of its deflexion may be read off.

The following experiments can be performed by means of such a thermo battery as we have just described, consisting of bismuth and brass, antimony and brass, or antimony and bismuth.

First Expt. with a bismuth and brass battery. Place the apparatus in such a position that the longer direction of the battery may coincide with the magnetic meridian, and have the same polar position as the needle. Heat the southern joint at *a* by holding under it the flame of a spirit lamp, and the north pole of the magnet will begin to turn towards the west, its deviation increasing as the temperature rises. Hence it follows that (by § 512.) the current proceeds from *b* to *a*, *i e.* from the cold to the heated end.

Second Expt., with a battery of antimony and brass.— Treat this in the same manner as the preceding, and the north pole will be deflected eastwards; hence the current goes from *a* to *b*, or from the hot to the cold part of the metal.

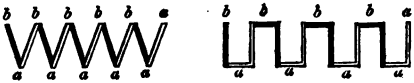
Third Expt., with a battery of antimony and bismuth. — The deviation in this case will be similar to that in the preceding, only that it will be much greater, the joint *a* being heated as before.

Cool *a* by the method given in the fourth experiment of the preceding paragraph, and the needle will be deflected in an opposite direction; the intensity of the current will be doubled by simultaneously heating *a* and cooling *b*. As a general rule, the sensibility of single thermo-electric batteries may be increased by using a double astatic needle, as in Fechner's thermo-galvanometer, *fig.* 197.

§ 531.

Compound thermo-batteries, or *thermo-electric piles*, may be constructed by combining a number of single ones on the same principle as voltaic piles or hydro-electric batteries are formed. Connect the single thermo-electric batteries by soldering together the two heterogeneous metals in pairs, so that the poles of the pile may end in two heterogeneous metals. Heat simultaneously all the junctions on one side of the pile, and cool all on the other, so that a heated point follows a cold one throughout; and the currents emanating from the poles will display an intensity proportional to the number of pairs. *Fig.* 200. is a scheme of such a combination, the dark lines representing the one metal, and the faint lines the other. Let *a* be the junctions to be heated, and *b* those to be cooled, or *vice versâ.* These thermo-piles have been variously constructed, according to the purpose to which they are applied, differing in form, dimensions, and the metals used as electromotors. Bismuth and antimony are the metals most generally employed, and the piles made of them are the most efficient and sensitive, but they cannot be used at high temperatures. If the heat to which the battery is to be exposed is great, platinum and iron should be used. The metals are commonly in the shape of four-sided prismatic bars, a few inches long, frequently only one inch in length, and a few lines in thickness and breadth.

Fig. 200.



These thermo-electric piles produce effects precisely similar to those brought about by the hydro-electric piles; *i. e.* if they consist of a sufficient number of pairs of adequate dimensions, they produce the same phenomena of light and heat, they excite the same physiological sensations, and exert the same chemical influence, but in a lower degree; because of the resistance to conduction that has to be overcome, which resistance prevents the currents generated by these piles, even when they consist of many pairs, possessing an intensity equal to that of currents emanating from hydro-electric batteries.

Munke describes one of these piles which he has constructed, the current of which produces all the effects named above: it consists of 81 pairs of antimony and bismuth bars, 27 lines long, 5 wide, and 4 thick. The pairs of bars are arranged in 9 rows of 9 pairs each, which, with their 8 metal connecting pieces, give 90 junctions on each surface of the pile. The under side stands in a tin vessel full of water containing ice and snow, while a copper plate of burning charcoal is laid on the upper side.

§ 532.

Our theoretical views and their practical application have derived considerable advantage from our increased knowledge of the nature and properties of thermo-electric currents. Undoubtedly the most important benefit, and that of which the most extensive use has yet been made, is the application of the thermo-electric current to measure temperatures in cases where other instruments were not sufficiently delicate, or where the temperatures were so extremely high or so very low that our ordinary pyrometers and thermometers could not be relied on; or, lastly, to measure the degree of heat in places where other kinds of apparatus could not be used. The strength of the current generated by the heat in a thermo-battery measures its temperature; the intensity of the current being estimated, as in hydro-electric batteries, by the deflexion of a magnetic needle. An apparatus of this kind is termed a *magneto thermometer.*

As yet it has been most extensively used to determine very minute differences of temperature. The *magnetic differential thermometer,* constructed for this purpose by Nobili, consists of a pile of bismuth and antimony, whose poles are connected with a delicate thermo-galvanometer. When in use the source of heat to be tested is allowed to operate on one half of the junctions, while the other half are kept at as low a temperature as possible. The delicacy of an apparatus of this kind is such that, according to Nobili's observations and comparisons, it is capable of measuring by the deflexion of the needle a difference of temperature of $\frac{1}{2200}$th of a degree. By the aid of such a delicate instrument, Melloni was enabled to carry on his beautiful and important investigations into the relations of radiant heat with the greatest accuracy, as well as to confirm them by experiments that admitted of no doubt (see § 384—389.). Von Wrede used the same means for determining the velocity of radiant heat (see § 381.).

The thermo-electric piles recently constructed by Nobili and Melloni are of various forms, according to the use to which they are to be applied. In that which Nobili calls "pila a scatola," the prisms of bismuth and antimony are so arranged that each half of the junctions stands near the other in a square. All the pairs are enclosed in a brass box of cylindrical shape, in which they are insulated, with respect both to the box and to one another, by having the interstices filled up with gypsum, wax, or resin. The two poles of the pile end on the outside of the cylinder in two binding-screws, by which they may be connected with the thermo-galvanometer. Both ends of the pile can be closed by a lid which shuts on over the cylinder. These piles are used chiefly for investigations into the phenomena of contact, for which reason their junctions are left polished, and, to increase their sensibility, the lid is so constructed that it can be filled with snow. — *Fig.* 201. represents this apparatus: *a* is the brass box which contains the thermo-pile; one set of junctions, *s*, is visible; *p* and *m* are the two binding-screws connected with the poles; wires go from these to the galvanometer; *b* and *c* are the two lids to shut up the box with. If the pile is intended for experiments on radiation, the junctions must terminate in sharp edges or points, blackened to increase their absorption of heat. They are placed either side by side in a square, or they form one straight line — the "pila a pettine," to investigate the phenomena of diffraction; or they are ranged within a circle, like the rays of a star; see *fig.* 202., where the rays of heat act on the junctions inside. This form is best adapted for the rays of heat concentrated by a convex lens. In all these piles that side of the junctions on which the rays are intended to act is furnished with a conical or parabolic reflector, widening outwards, as is shewn at *c*, *fig.* 201., in which the rays of heat may be received, while the other side is secured against their influence by being closed with a lid.

Fig. 201.

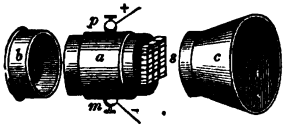
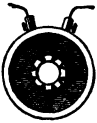


Fig. 202.



For the first idea of a *magnetic pyrometer* we are indebted to Becquerel. This distinguished philosopher made use of a thermo-battery of copper and iron, which he connected with a galvanometer that he regulated in such a manner as to express the deflexions of the needle in values of the electric current. Suppose now some definite intensity of the current had been ascertained for some particular high temperature of one of the junctions, a temperature, however, that could be appreciated by the common thermometer, while the other two are kept at the freezing-point; if any additional heat beyond the range of the thermometer be applied to that junction, a still further deflexion of the galvanometer would ensue, and this higher temperature would be immediately given by the deflexion in degrees of that particular thermometric scale which had been used in valuing the original deflexion. Pouillet's magnetic pyrometer acts on the same principle; it consists of a gun-barrel, to which are soldered two platinum wires that are connected with a thermo-galvanometer made by coiling a strip of very thin copper some twenty-five times. The construction of this galvanometer in other points resembles that of the sine compass (§ 522.); and, by a formula Pouillet gives, we may calculate from the angle of the needle's deflexion what is the temperature of the junction exposed to the heat. By means of such an instrument the fusion-point of most of the metals has been determined (§ 401.) Pouillet also used the thermo-electric battery for determining the maximum degree of cold. He endeavoured to ascertain the temperature at which quicksilver freezes and sulphuric æther combined with solid carbonic acid begins to solidify. He used a battery of bismuth and copper, and found the degrees of cold shewn by it to agree exactly with those given by an air-pyrometer and a spirit of wine thermometer with which he compared them; he considered, therefore, that the indications of this apparatus are proportional to the differences of the temperature as low as $-100°$ centigrade $= -148°$ Fahr., or 180° below the freezing point.

The third use to which these thermopiles have been applied is to measure the temperature of places; they have been employed in estimating the temperature of the sea, and that of the earth's crust at various depths below the surface, as also that of the atmosphere at different elevations. The simple batteries as yet used for the purpose consist of an iron and copper wire, whose ends are soldered together; the length will vary according to the distance of the point whose temperature is to be investigated. One of the junctions must be at this place, and the other at the station where the observations are made. A thermo-galvanometer is connected with the battery, and shows by the deflexion of the needle what is the difference in the temperatures of the two stations. Now to measure this, Peltier immersed the junction at the place of observation in some fluid whose temperature he raised or lowered, as the case might be, till the galvanometer needle stood at zero, when the temperature of both the junctions must be equal. A thermometer standing in the fluid showed the heat at this point, and at the same time also that at the more remote junction. These measurements will not always give perfectly accurate results, especially when the difference between the temperatures is small; and if the length of wire to be traversed by the current is considerable, its intensity will sometimes be inadequate to overcome the resistance to conduction and affect the magnetic needle.

It is deserving of remark that by means of a thermo-electrical apparatus, such in principle as we have just described, but of course modified somewhat in form, Becquerel, Brechet, and Dutrochet have succeeded in obtaining important estimates of the vital heat of cold-blooded animals and living vegetables.

The application of thermo-batteries to this use led Peltier at length to the important discovery, that a hydro-electric current in its passage through a single thermo-battery, is capable of generating either heat or cold at its junctions; the former, when its direction is opposite to that of the thermo-electric current which is generated by raising the temperature of the junctions; the latter, when its direction is opposite to that of the current produced by cooling the same points. The apparatus best adapted for testing the difference of temperature caused by a hydro-electric current is *Peltier's Thermo-electric Cross*, which consists of two strips of different metals, *ex. gr.* antimony and bismuth, laid one over the other in the form of a cross, and soldered together at the point of intersection. Two heterogeneous metal ends of such a cross are connected with the poles of a single hydro-electric battery, and the other two with a thermo-galvanometer. As the stream flows through the junctions, the needle of the galvanometer is deflected, from which we infer whether these points have been heated or cooled. The voltaic current may be allowed to act alone for some minutes; then suspend it and connect both ends of the cross with the galvanometer; the same result is obtained. If the cross be made of antimony and bismuth, the junctions are heated when the current proceeds from the former metal to the latter; on the contrary, if they are cooled it goes in the opposite direction. Corresponding results have been obtained with other thermo-electric combinations, and as a general rule, it seems that heat is elicited when the positive current passes from a bad to a good conductor; that cold is produced when these circumstances are reversed. Von Lenz so lowered the temperature of a junction in an antimony and bismuth battery by the voltaic current as to freeze water.

§ 533.

Light is mediately a cause by which the electrical equilibrium in a body is disturbed, if it produce local heat, especially in those parts where heterogeneous substances touch. This effect of sunlight is easily explained by attributing it to the thermal influence of the solar rays (§ 425.); but the inferences that we seem to be justified in drawing as to the warming of the earth's surface by the sun are of special importance. Since the crust of our earth may be regarded as a battery of heterogeneous matter, and since its thermo-electric currents have for the most part the same path as that in which its heat advances, it has hence been inferred that during the rotation of the earth from west to east, the heating of its surface by the sun's rays goes on in an opposite direction, viz. from east to west, and that to this the electric currents owe their origin; for they hold on their course uninterruptedly in the same direction on and within the earth's crust, in lines parallel to the equator and its parallels. This theory, which is held by most modern philosophers, was first broached by Ampère.

The importance of this theory induced several scientific men to institute experiments to determine the actual existence of these currents. In the year 1830, Fox performed a series of experiments in the mines of Cornwall, by connecting two distant stations in the same vein with the wires of a galvanometer. He thus ascertained the existence of electrical currents of different degrees of intensity within the earth, their direction in some cases running from E. to W., in others from W. to E., and when the stations were at unequal depths below the surface, the electric current was generally downwards; Pentherick and Bennett verified this last observation in their experiments in other mines. Professor Reich's experiments, which he carried on in 1838 and 1839, in the mines of Saxony led to similar results, inasmuch as he found the direction of the currents to depend on the geographical situation of the place, and on the depth of the station below the surface.

Edmund Becquerel has since made us acquainted with another electrical influence of light. From a series of minute and ingenious experiments, this philosopher found that the chemical rays (§ 358.) of the sun and of artificial lights exert such an influence on plates of metal immersed in any fluid they can decompose, as to cause electrical phenomena which could not be produced by means of heat alone, and that the plates thus exposed to these rays became positively electrified. The fluid must be one chemically acted on by light. Subsequent experiments have shown that the chemical action of light is not the sole exciting cause of these currents, but that the radiation of the metal exerts a powerful influence on this phenomenon. That light alone, without any chemical action, might produce this effect, can be shown by the following experiment. A vessel was divided into two parts by means of a capillary partition, and each part was covered with an opaque screen. Both compartments were then filled with the same fluid, and a strip of platinum placed in each; the connection was established by means of a galvanometer. Under ordinary circumstances, no electrical current would be generated in the apparatus; but on removing the screen from either of the divisions so as to allow the light to fall on the platinum, the needle of the galvanometer was considerably deflected from its original position of rest.

§ 534.

Becquerel's experiment, which we have just described, leaves us no room to doubt that Heat is the alone immediate and sufficient cause by which electricity was excited, and that no chemical influence whatever operated to produce it. But as yet no satisfactory conclusion has been arrived at, as to the mode or kind of influence heat exerts in thus disturbing electrical equilibrium; thus much at least has been ascertained that, in this class of electrical phenomena, the internal texture of the bodies, and especially their crystalline structure, plays an important part; if, too, as we have already shown, a change in the molecular relations of bodies be the primitive cause by which electrical influences are called into existence, heat may induce the required change in a variety of ways.

Becquerel is of opinion that if the metals are classed according to the degree in which they become positively electrical by contact with each other, their order will be found to agree with that in which they would stand if ranged according to their radiating power; hence he conjectures that the thermo-electrical properties of bodies stand directly related to their radiating power. He further holds that, when the caloric meets with any resistance to its motion and propagation in bodies, it resolves itself into its two factors + and − electricity; that experiments have proved the former to be the more powerful; it therefore penetrates through the resisting medium, and hence the (positive) electric current passes from the heated towards the cooler parts. He also assumes, that heat can alone be the exciting cause by which electrical equilibrium is disturbed in bodies, that by its expansion of the minutest particles in a body they are made to recede one from another, and that it acts in the same manner as in the mechanical separation of bodies and their constituent particles (§ 526). Every particle more heated than its neighbours will attract more + electricity and repel in all directions the − electricity, and thus the direction of the thermo-electric current is shown by the progressive warming of one particle in a body after another. Nobili, who has built up his theory on the same assumption, considers heat as the common principle of all electrical phenomena, and is of opinion that electrical currents invariably pass from the hot to the cool body; he speaks of the electric currents as discharging the caloric in one or other direction, and thinks that they display the phenomena of heat and incandescence when the caloric is in excess, and that to the same cause is to be attributed the other effects which have been already noticed. He accounts for the high velocity with which electricity is propagated by supposing the electric current to be properly an undulation which communicates to the one extremity any difference of temperature existing at the other.

§ 535.

Magnetism is also an exciting cause of electrical action: the condition of electrical neutrality is affected in a remarkable manner by the magnetic polarity of bodies, and if they are conductors of electricity a current will be generated closely resembling in its nature the currents derived from other sources, though its duration and direction depend on peculiar laws. The electrical phenomena generated by magnetic influence are classed under that branch of natural science known as electro-magnetism, which will be treated of at length in the concluding section of this work.

VI. ATMOSPHERIC ELECTRICITY AND THE ELECTRICAL PHENOMENA OF LIFE.

§ 536.

The shell of air and vapour, which we call the atmosphere, is that part of our planet in which the electricity liberated by various processes accumulates; it constitutes in fact the great reservoir of sensible electricity, our solid earth being rather the field in which this mighty power is again collected and neutralized. The atmosphere is therefore the region in which the phenomena of *atmospheric electricity* are displayed on a large scale: their origin and operations are to be explained by reference to the observations made and the laws discovered, as given in the preceding sections.

The existence of sensible electricity in the atmosphere may be readily proved by fixing a glass tube on a wooden stick, a fishing rod will do, several feet long; to the tube fasten a pointed piece of brass or copper wire; erect this in the air, and it will act as an insulated conductor to attract the electricity; the conduction may be accelerated by sticking a piece of phosphorescent touch-wood on the point of the wire. Now connect the wire by means of a second wire with a delicate electrometer, and the latter will show the electricity conducted to it from the atmosphere.

§ 537.

Sensible electricity is found in the atmosphere at all times and in every state, but it varies both in kind and intensity. The following general results have been arrived at by the investigations of many scientific men into this subject. When the air is clear and serene, its electricity is generally positive, but when the weather is damp or rainy, it is negative. Its intensity varies with the height of the different strata; it is also affected by the time of the year and of the day, and by the tranquil or windy state of the air. The electricity is more powerful in the higher regions of the atmosphere than it is near to the surface of the earth; it is stronger in winter, and especially in frosty weather, than in summer, and when the air is still, than in windy weather. Atmospheric deposits, such as rain, snow, &c., are sometimes positively and sometimes negatively electrical; Schübler's observations go to prove that this depends on the quarter from which the wind blows. Generally speaking, when the wind is in the north, the deposits are positive, when it is in the south, they are negative, and between these there is a constant interchange; the electrical condition of the earth is invariably opposite to that of the atmosphere; hence, at a certain distance above the surface of the former, in an open country, at the height of three or four feet, the antagonist electricities neutralize each other. A periodic variation has been noticed in its intensity, the aërial electricity attaining a maximum and minimum twice every day. Its intensity is lowest during the night, it rises at sunrise and during the fall of dew, and attains its maximum a few hours after the sun is above the horizon; from that time it diminishes till it reaches the minimum, an hour or two before sunset; as the sun sinks below the horizon, it rises rapidly while the dew is falling, and in a few hours attains its second maximum.

> De Roma, Wecke's, and Henry's experiments with electrical kites first proved that sometimes the sensible electricity accumulated in considerable quantities in the upper regions of the atmosphere. The electricity they conducted by this means to the earth's surface produced effects far greater than have as yet been performed by the most powerful electrical machines ever constructed. — All experiments of this kind are, however, attended with danger, especially if conducted during a thunder-storm, as was shown in the case of Professor Richmann, of Petersburg, who was struck dead by a flash of lightning which he drew from a cloud on the 6th August, 1753.

§ 538.

The sensible electricity, which exists in the atmosphere, owes its origin to many different causes; but though some of the most distinguished philosophers have investigated the subject, no perfectly satisfactory explanation has as yet been offered. Among the probable causes to which it is supposed to be owing are, the friction of the particles of air one against another, the contact of strata of air of unequal temperatures, the processes of combustion and vegetation, the formation of vapours and their condensation. Since we know by experience that when two bodies are rubbed together the warmer becomes negatively electrified and the other positively (§ 481.), and since the heat of the strata decreases with the heat of the atmosphere, some philosophers have conjectured that in these laws we are to look for an explanation of the fact that, as the height of the strata increases, they become more positively electrical. Pouillet, on the contrary, considers that the process of combustion, evaporation, and vegetation, which are carried on uninterruptedly at the earth's surface, are the main sources from which the atmosphere derives its supply of electricity: this view he has endeavoured to support by a series of experiments, for an account of which the reader is referred to his work. The correctness of this assumption, on which the counter experiments of Pfaff have thrown a degree of doubt, requires a fuller investigation before it can be admitted to have been proved. The indubitable evidences of sensible electricity, which attend the different atmospheric deposits, are in favour of the aggregate conversion of aqueous vapours exerting a considerable influence on the generation of atmospheric electricity; Clarke has even tried to show that a connexion subsists between the variations in the quantity of vapours and electricity in the air. — Perhaps after all, it is more correct to assume that several of the causes named above, and perhaps others besides, which have not yet been recognized among the number, operating together, contribute to maintain the atmosphere in a state of positive electricity, and the earth's surface in a state of negative electricity: as the air is a very bad conductor, Kämtz compares the atmosphere to a large electrical battery, whose negative coating is the earth's surface, and whose positive coating is formed by the upper strata of the atmosphere.

§ 539.

The principal phenomena whose origin we are accustomed to attribute to the accumulation of sensible electricity in the atmosphere, and its consequent neutralization, are, the *electro-meteors*, as they are called, that is to say, *thunder-storms, sheet lightning, the luminous appearance of pointed objects, the aurora borealis, waterspouts, and whirlwinds.*

The best known and the grandest of these phenomena are *thunder and lightning*, usually accompanied with rain or hail.

Thunder storms have been accounted for by attributing them to the formation of clouds, by which they are always preceded. It is well known that they generally occur in the warmer part of the year, and that they are most frequent in the torrid regions, because the thermal state of the atmosphere is then and there in the best condition for taking up a large quantity of aqueous vapour. Now if a stratum of air fully saturated with aqueous vapour be cooled but slightly from any cause whatever, the necessary condition is thereby fulfilled for a change in the aggregate form of the vapour, which is converted into minute drops which form into mists and clouds. This process will go on under these circumstances much more rapidly and abundantly than if a cooler air, saturated with aqueous vapour of less density, had lowered its temperature the same number of degrees. The condensation thus produced disturbs the electrical equilibrium before subsisting in the vapour, and the + electricity accumulates in the conducting surface of the drops. In proportion as this formation of mist goes on the clouds become thicker, the drops of vapour come together near enough to touch, and all their free electricity is driven to the surface, which has the sharpest boundary; the tension of the electricity which is thus extending must necessarily increase, just as it does in an insulated conductor that is charged (§ 482.). Such clouds are then to be regarded as great insulated conductors floating about in the air, which cannot but act agreeably to the laws of polar attraction and induction (§ 475. 478. 483.) on any bodies that come within the range of their influence. The origin of clouds negatively charged is accounted for thus: it is supposed that the positively electrified clouds, which float about in the higher regions of the atmosphere, by their inductive influence on other clouds nearer to the earth than themselves, attract the — electricity from the latter, whilst the + electricity discharged into them makes its escape to trees, hills, and other projecting objects on the earth's surface.

The clouds thus charged with electricity, like all other electrical bodies, exert a tendency to saturate themselves each with the antagonist electricity, and thus to re-establish a state of equilibrium. This interchange takes place either between oppositely electrified clouds, or between the latter and the earth's surface. In the former case there is commonly a mutual attraction of the clouds, which will account for their moving in opposite directions towards each other, as also for the changes in form which they undergo. If the equalization of their electricities happens suddenly, the intervening stratum of air is penetrated by the *lightning*, which is merely a strong electric spark; its path is usually zigzag, probably in consequence of the resistance it meets with in passing through the air it has itself condensed; even the longer sparks given off by an electrical machine are of a zigzag shape. Several flashes frequently follow each other in quick succession, which is the case when, on account of their relatively low conducting power, the clouds do not completely discharge themselves at once. This corresponds to the residuum of sensible electricity, which accumulates on the surface of a battery that has been discharged, and thus causes a second or third discharge.

The *thunder* is produced simultaneously with the lightning. It is a loud report caused by the sudden rupture and dispersion of the air by the passage of the flash of lightning; and is perceived to happen, on a very small scale, on discharging a battery. If the observer be at no great distance from where the explosion takes place, he will hear only a sudden report of short duration; but in proportion as the thunder becomes more distant it will be accompanied with a peculiar *rolling sound.* It is most probable that this rolling or pealing of the thunder is occasioned partly by the frequent compression and disruption of the air by the lightning in the course of its passage, sometimes miles in length, through the damp strata of air, which act as conductors; partly also to the different distances from which the sound comes to reach our ears; and partly to the recoil of the waves of sound from the earth, the sea, and even from the clouds. Kämtz conjectures that it is modified also by the interference of the undulations. By these various causes the original report is so affected, that thunder heard in a plain country sounds differently from that heard in a hilly one, and this again from that heard at sea; indeed, at no two places probably is it exactly alike. From the time which elapses between the flash and the report, the distance of the cloud whence they proceed may be calculated by the observer according to the laws which are known to regulate the velocity with which sound travels.

The electrical discharges from the clouds fall the more readily on objects at the earth's surface in proportion as they favour the inductive action of the clouds, and aid the passage of the lightning by the good conducting structure of their materials, by being well connected with the ground, and especially by their height and figure, which should be pointed at the extremity. Hence lightning most frequently strikes high houses, towers, trees, masts of ships, and the like.

The effects produced by the lightning in its course through bodies depends principally on their conducting power. They resemble, on a grand scale, the effects of powerful sparks from an electrical battery. When it strikes any object it proceeds from that point along the best conductor that offers itself, so that it does not always choose the nearest path by which to reach the ground. On arriving there, it is neutralized by the opposite electricity of the earth, and all its influence ceases. If the conductors be stout bars of metal, or any similar objects, which offer but a trifling resistance to the passage of the lightning, the discharge will take place without leaving any perceptible trace of its influence. If this is not the case, as when the lightning strikes either bad conductors, or conductors of insufficient capacity, or those whose continuity is broken so that there are intervals over which it must leap, or through which it must penetrate, then its effects are extremely varied. It fuses or calcines the substances through which it passes, as when it traverses wires that are too fine. It sets on ~~fire such~~ bodies as are easily combustible. It vitrifies earthy substances, ~~especially~~ such as are at all sandy (*a*). It splits into shivers those solid bodies which ~~are bad~~ conductors; and is destructive to life, both of man and of the lower ~~animals~~ (*b*). Sometimes a flash is emitted from the earth without any electricity being discharged from a thunder-cloud. This phenomenon is thus explained: when a cloud floats just above terrestrial objects, and by induction accumulates in them a great quantity of the opposite electricity, and then suddenly discharges itself against a cloud higher in the air than itself, the sudden recoil of the latter occasions the phenomenon.

(*a*) When the lightning strikes a sandy soil it sometimes penetrates to a depth of 20 feet, fusing the gravel through which it passes, so as to give the appearance of a bore or tube; to these holes the name of *fulgurites* has been given, and their electrical origin, which was long held as doubtful, has been fully proved by Beudant and other French philosophers, who artificially produced similar effects by means of an electrical battery.

Almost all these cavities which have been traced to a greater depth than some 20 or 25 feet are found to terminate in a collection of water; so if we compare the lightning to an electric spark, the cloud to the conductor, the mass of water to the discharger, then the superincumbent bed of sand will answer to the interposed substance which is pierced by the passage of the spark.

(*b*) On the morning of June 2., 1839, a flash of lightning struck a battalion of French infantry on their march from Mezières to Weissenburg between Mouzon and Stenay: 200 men were struck by it to the ground, and on rising blood was seen to issue from their mouths, noses and ears: two men were killed on the spot.

The precautions to be taken in order to secure ourselves from a stroke of lightning will be readily seen from a consideration of the preceding paragraphs, and from a knowledge of the laws which regulate the action of the electricity obtained from the machine. The chief thing to be attended to is to avoid coming too near to any good conductors. If out of doors, do not take refuge under a tree or any other high object, do not move with such velocity as to accelerate the process of evaporation, walk in the middle of the street rather than near the houses: if within doors, place yourself in the middle of the room, away from the walls, bell-pulls, or any other conductors of electricity.

Water-spouts and *whirlwinds*, as also *hail*, which not unfrequently accompany storms, are among the aërial phenomena that have not yet been satisfactorily accounted for; atmospheric electricity may however be regarded as at least a co-operating cause by which they are generated.

Water-spouts observed at sea, and the pillars of sand seen generally in the great deserts, resemble huge funnels depending from the clouds. They have a remarkably quick and tortuous motion, and frequently emit flashes of lightning from their interior. When they arise at sea, the water immediately beneath them is put into a state of rotation; by which means it is drawn up to the water-spout. When this phenomenon occurs on land, dust, sand, and other bodies are raised in like manner. The force with which this motion is generated is prodigious. The masts of ships have been broken by it, the vessels themselves have sometimes been raised up by it and then sunk; whilst on land trees and even houses have sometimes been unable to withstand its violence.

There is a very difficult problem to be solved with regard to hail, which is evidently formed in the atmosphere, and which occasionally falls in pieces large as a man's fist, *viz.*, *how* so many thousand tons of ice can be formed and supported in the air?

§ 540.

After Nollet and Winkler had almost simultaneously (about the middle of the last century) discovered the electrical nature of lightning, Franklin (1753) applied himself to invent some method by which the lightning might be conducted to the ground, and its destructive effects guarded against. The *lightning conductors* which he invented were rods of metal, of sufficient thickness, terminating in a point, which projected some distance above the highest part of the building near which they were fastened; their continuity was unbroken throughout, and their lower extremity was driven some way in the ground: by this simple contrivance buildings, especially such as are filled with inflammable materials, are secured against the destructive action of lightning; the apparatus, with slight modification, has been applied also to ships. In the erection of a paratonnere the object to be secured is, that when it causes the discharge of an electric cloud, it alone should conduct the lightning to the ground without the building it is intended to protect or any of the neighbouring ones contributing in the slightest degree to re-establish the electrical equilibrium.

Since the original invention of this most useful apparatus various improvements have been introduced in its construction, and an attempt has been made to find some method of measuring its protective power. In the erection of conductors the following rules are generally attended to; if of iron the upright rods are generally about 2 inches thick and they rise at least from 5 to 6 feet above the highest parts of the building they are to defend, their ends are armed with a truncated point generally of copper gilt. It is assumed that a paratonnere of this kind is effective within a circle of 30 feet, that when several are erected they ought not to be more than 60 feet asunder. According to the experiments of Professor Charles it would seem, however, that a paratonnere does not protect any object whose distance exceeds twice its own height above the object. A metallic connexion is carried on from the projecting rod uninterruptedly to the ground: for this purpose a thinner bar, generally about ½ an inch thick, is used; but sometimes strips of other metals are employed, and occasionally even wire. Whatever kind of conductor may be selected, it is necessary that it should go over the roof and not merely down from the upright rod above the building; care should especially be taken that wherever the parts are joined there should be a pure metallic connexion; further, it is advisable that it should be carried at some little distance from the roof and walls of the building; that it should not pass through any combustible substance; that it should be kept away from any metal in the building itself, such as bell wires and the like; that if the roof be of metal the conductor should be carried clean over it and over any metal gutters and spouts. The ends of the conducting rods or wires ought to be carried to a place where the earth is itself a good conductor; if into a pool of water so much the better. If this cannot be done, select as damp a spot as can be found, and let the conductors terminate in three or four divisions a few feet under ground and not close to the building. Powder-magazines, laboratories, and similar edifices, containing substances that would readily ignite, require to be secured with especial care against lightning. To prevent the lightning communicating at all with the building, tall poles like masts rising higher than any part of the building are placed round about it at distances of from 6 to 10 feet; the tops of these masts are armed with paratonneres, and, according to Professor Charles's observations, the distance of one mast from another should not exceed one-fourth of its height. In the construction of edifices requiring extra care to secure them from lightning all unnecessary projections should be avoided and as small a quantity of metal as possible should enter into their construction.

The phenomena of lightning, and the destructive effects which sometimes follow when it strikes a building are exemplified by means of a well known piece of apparatus called a *thunder-house*, used with an electrical machine; by it the utility of lightning conductors is illustrated, and the identity of the lightning and of ordinary electricity is fully established.

§ 541.

The *lambent lightning*, usually seen during the warm summer evenings playing in the horizon, is another well-known electrical phenomenon. It consists in a succession of luminous flashes rapidly following each other and each of but transient duration. No report like thunder is heard to follow and the light is often visible at the same time in the most opposite regions of the horizon extending over a very considerable space. It has been established beyond doubt that in many cases it is owing to the flashes of lightning which attend storms happening at that very time at places below the horizon; but in other instances, Schübler believes it to be an electrical phenomenon altogether independent of any thunder-storm, owing to the efflux of strongly accumulated electricity which meets with no antagonist electricity in the neighbouring strata of clouds; similar therefore to what obtains in the experiment with the lightning table described in § 493.

§ 542.

Similar electrical phenomena, but less generally known and less frequently noticed are those tufts of light occasionally visible when the air is in a highly electrical state on pointed objects, such as the tops of the masts and the ends of the sail-yards of vessels, on the tips of lightning conductors, on the ends of bayonets, and sometimes even on the ears of horses; the ancients gave to this light the name of Castor and Pollux: in modern times it has received various names, as St. Elm's fire, Helen's lights, &c. The light is seen to flow from such bodies as we have just named for a length of time, the discharge being attended with a crackling noise; it produces no perceptible effects, and is in all probability owing to the equalization between the electrical tension of the atmosphere and earth, resembling the emission of electricity from pointed bodies towards the conductor of the machine.

§ 543.

The *Polar lights*, the *Aurora Borealis*, and *Australis*, are luminous appearances in the horizon, less transient in their duration than either the lightning or the phenomenon described in the preceding paragraph; indeed they are sometimes visible for hours. They are of most frequent occurrence in the higher latitudes, more rare in the temperate zones, and within the tropics they are scarcely ever seen. In the northern hemisphere the illuminated part surrounds the north pole, in the opposite hemisphere it surrounds the south pole; hence the respective names of *borealis* and *australis* applied to the aurora. When the figure is perfect, which however it rarely is, it consists of a luminous strip of a circular form, enclosing with the horizon a dark segment of a circle whose centre seems to lie in the magnetic meridian. This arch of light undergoes many changes in the beautiful colours which compose it, and emits many flashes of light. From time to time it throws up sparks of light of all colours, and in every direction; these frequently reach to the zenith and form a kind of crown. The greatest height to which this radiant light extends in the atmosphere is somewhere about fifteen miles. Sometimes the entire heavens appear illuminated above the arch to the very zenith; it is asserted that when the northern lights are unusually brilliant, very peculiar noises have also been heard.

From experiments and observations made on this subject, especially by Hansteen, it appears that the polar lights do frequently, but not always, affect the magnetic needle, deflecting it several degrees, just as the electric current deflects the galvanometric needle (§ 450. and § 512.), whereas if a needle of copper or any other metal be substituted for the magnetic needle, no such effect follows. There is a great similarity between this phenomenon and the appearance presented on exhausting a glass vessel and then discharging a stream of electricity into the vacuum, as is done in the *electrical aurora borealis*, § 493. Hansteen's observation is worthy of notice, that, shortly before the aurora borealis is seen, the terrestrial magnetism displays an unusual intensity, which however diminishes on the appearance of these northern lights, and gradually sinks again to its ordinary standard.

From the resemblance of this phenomenon to others of an electrical nature, and from the fact that it frequently affects the magnetic needle, it is held almost universally to be of electric origin. Thienemann, who during his residence in Iceland had repeated opportunities of seeing this phenomenon, considers it to be caused by electrical discharges in the fine feathery clouds in those northern regions where thunder-storms are unknown; the noise, too, which has sometimes been observed to accompany the flashes of light, is by him referred to an electric origin.

§ 544.

It is generally believed that we are warranted in saying that while the functions of life are performed, an uninterrupted development of electricity is maintained between the nerves and muscles of animals, at the surface of the skin, and especially in heterogeneous organs. The precise origin from which this supply of electricity is derived is still unknown to us; some consider it to be an effect of the organic process of life in general; others that by means of the contact, or by some chemical difference in the nerves and muscles, the electricity existing in the animal subject in a state of equilibrium, is made to acquire a degree of electrical tension, and that this constitutes the source from which it is supplied; others again consider electricity and nervous energy to be identical.

Soon after Galvani's important discovery, by which it was thought that the existence of a peculiar animal electricity had been ascertained, Alexander von Humboldt, Pfaff, and others, found that when the spinal nerve and the muscle of a frog's thigh were placed in immediate contact or were connected with an insulated piece of muscular flesh, contractions took place in the latter just as if it had been brought into contact with dissimilar metals. In like manner traces have been detected of an electric current in living bodies, by connecting two remote portions of a nerve, or of the muscle belonging to it, with a very delicate galvanometer.

Dr. Donné of Paris is one of those who seek for the source of this electrical excitement on the surfaces of the inner and outer skins, attributing alkaline properties to the former and acid properties to the latter. He made one end of a platinum wire to communicate with the outer, and the other with the inner skin of the mouth; within the circuit thus formed he introduced a delicate galvanometer, and found evident traces of an electric current which answered to this hypothesis. Matteuci, however, is strongly persuaded that a current produced thus after the death of an animal, soon ceases, and that consequently it could not have been owing solely to the chemical influence of the fluids transpired through the two skins. Wilson Philipp, on the contrary, showed how in certain cases the functions of the nerves might be discharged by a hydro-electric current, for having destroyed the action of some of the nerves leading to the stomach of a dog, he restored their suspended action by connecting the severed ends with a feeble galvanic current.

That a peculiar electrical energy resides in the substance of the nerves, which can in some animals be called into play at pleasure, is clear in the case of the *torpedo* and the *gymnotus* or *Surinam eel*. These fishes are distinguished by an extraordinary abundance of nerves, and particularly by a peculiar organization, by virtue of which they are enabled at pleasure to communicate electric shocks to any animals that come near them. These shocks are very like those given from a Leyden jar, or from a voltaic battery of a large number of plates; they succeed each other so rapidly that men, horses, and other large animals are stunned and even killed by them. Anatomical investigation has shown that the electrical organ in these fishes resembles in its construction a hydro-electric cell battery: it produces not only the physiological effects noticed above, but others of an electrical nature strictly identical with those generated by voltaic electricity. Thus in this electrical action conductors and non-conductors have been found to occupy the same relative positions towards each other. By the current these creatures emit, luminous, thermal, chemical, and even magnetic effects are produced.

The electrical organs in all fishes of this class are similarly constructed; but it is not situated in the same part of the body in them all. The torpedo has been examined with the greatest attention: in it, it is found to consist of a combination of single cells arranged like a galvanic pile, a transverse membrane closes them, and they contain a peculiar fluid. Numerous nerves run to these dividing membranes and probably fulfil the same office as the dissimilar electromotors of a hydro-electric battery.

If the electrical organ of one of these fishes be touched externally at two different points, either immediately or by means of a conductor, a shock will be experienced instantly. The wider the points touched are from each other, the more powerful the shock; several persons may receive it at once if they form a circle by laying hold of hands, having previously moistened them with water; the first person should then touch the belly, and the last the back, of the fish. The current and its influence will be interrupted by imperfect conductors. Positive electricity is obtained from the back, and negative from the belly, as has been shown by means of delicate electroscopic apparatus. John Davy was the first who measured the chemical intensity of this current by its decomposition of water and the metallic salts. Its thermal force he ascertained by means of an electric thermometer; its magnetic influence he tested partly by its deflection of the needle, and partly by its magnetizing needles. Matteuci, and more recently Lineari, have succeeded in getting distinct sparks from these creatures.

Electricity seems to play an important part in the various stages of the development of plants. Thus flashes of light have been seen to be emitted from many plants in full flower soon after sunset on sultry days. It has further been ascertained, by means of galvanometric experiments, that electric currents are generated in the interior of their substance, although their intensity is but small; and that an uninterrupted development of electricity is maintained by the exhalation of carbonic acid in the atmosphere, especially during the germination of the seed, and, indeed, throughout the entire process of vegetation.

The luminous phenomena in plants have been most diligently noticed by Zawadski, who observed them to happen principally in orange-coloured flowers (Calendula officinalis, Tropæolum, Lilium bulbiferum, Tagetes patula and erecta); that they occurred most frequently in the months of July and August, and that the same flower discharged a number of flashes in succession. — Dr. Donné has performed a number of experiments in the course of his investigations into this subject. He has found that in many fruits the current runs from the stem to the eye, while in others it flows in an opposite direction. Blake, who has established the existence of these currents by similar experiments, thinks he has discovered that they run from the stems to the surfaces of leaves; that he has verified their course to be as has been just said, by the chemical decompositions they effect; that, lastly, the leaf itself is rendered positive, and the ambient air negative. — Pouillet has rendered essential service to this branch of science by discovering that positive electricity is given out from plants when germinating. This he ascertained by connecting some that were in this stage of vegetation with a condensing electroscope. From his experiments he inferred that a surface of 1000 square feet would give out sufficient electricity to charge the most powerful battery.

SECTION V.

ELECTRO-DYNAMICS,

OR THE PHENOMENA OF ELECTRO-MAGNETISM AND MAGNETO-ELECTRICITY.

§ 545.

We have already proved, in many passages in the sections devoted to Electricity and Magnetism, that a great similarity in many points obtained between these two forces. This was particularly evident in the exact coincidence of their principal laws, viz., in those of polar attraction (§ § 437. 475. 481.), and in those of induction (§ § 439. 478. 483.). But many other phenomena, and especially the influence of electricity under various circumstances on both natural and artificial magnets, and on bodies capable of being magnetized, lead us to infer an intimate connexion between these two agents.

> The following are some among many phenomena of this class: — It was noticed that steel rods, and even stones (probably loadstones), acquired magnetic properties when struck with lightning. Sometimes common needles were magnetized by passing electric sparks through them. It was also observed that a ship's compass not unfrequently deviated from its normal position, when the masts of the vessel came near to a thunder-cloud. Thus in the year 1676, when a fleet was sailing to Barbadoes, one ship was struck by lightning, and no small surprise was excited by her immediately sailing back towards England. On inquiry it was found that the flash had reversed the poles of her compass needles.

Within a very recent period some most important discoveries have enabled us to prove, on scientific grounds, on what this connexion depends. The facts on which the whole proof rests are the following, viz.: —

1.) That every metallic conductor through which an electric current passes, acts on magnets suspended freely, and shews magnetic properties.

2.) That electric currents exert on each other influences closely resembling those which they exert on magnets.

3.) That a magnet acts on an electric current precisely as another current would have done.

4.) That electric currents in conductors in like manner excite such currents. And, lastly,

5.) That magnets can in like manner excite electric currents, and the other electric influences dependent on them.

All those phenomena in which electricity calls forth magnetic influences belong to *Electro-magnetism;* those in which electric action is excited by means of magnets are comprised under *Magneto-electricity.* Since, however, as far as our present experience has demonstrated, the electricity set in motion is the fundamental cause of all these effects the name of *Electro-dynamics* has been given to this recent branch of physical science.

Ritter and Yelin in the last century threw out some conjectures as to the internal connexion between electricity and magnetism, and their probable identity; but it was not until 1820 that Oersted, of Copenhagen, discovered the first effects of an electro-magnetic, and in 1832 Faraday those of a magneto-electric character.

I. ELECTRO-MAGNETISM.

A. *Influence of the electric current on magnets suspended freely.*

§ 546.

The first discovery made by Oersted, by which the road to this fertile field of science was first laid open to philosophers, consisted in this: that *an electric current transmitted near to a magnetic needle deflects it from its normal position.* This deflexion, which at first seemed either to occur or fail in a manner altogether peculiar and uncertain, was found, on closer examination, to obey a universal and unvarying law; which is thus expressed in Ampère's brief and universal terms: *That the north pole of a magnet is invariably deflected to the left of the current which passes between the needle and the observer, who is to have his face towards the needle, the electric current being supposed to enter near his feet, and to pass out near his head.* The needle, therefore, as far as the directing force of terrestrial magnetism permits, endeavours to take up a position perpendicular to the direction in which the current flows. This effect is not altered if, between the conductor of the current and the magnetic needle, there be interposed either good or bad conductors. Unmagnetized needles, and such as are made of non-magnetizable substances, are acted upon in no such way by an electric current.

As before, by current is always to be understood that of positive electricity; the law just given and all that will be said about the current and its direction, is applicable to the negative one, if every thing be exactly reversed.

Since, as we have had occasion to remark before (§ 488. and 497.), the permanent electric current is more powerful and certain in its effects than the momentary one, the hydro-electric current will principally be used in these experiments, although we have seen several magnetic phenomena produced by frictional electricity; and since thermo-electric currents are equally permanent with the voltaic, their magnetic effects agree exactly with those of the latter.

At first voltaic piles were used for the performance of electro-magnetic experiments; but when it was found that the magnetic effects, in which, generally speaking, there was no very great resistance to conduction to be overcome, depended principally on the *quantity* of electricity set in motion, a common hydro-electric battery, with a pretty large effective surface, came to be used in its place; the kind generally used was either an Oersted's trough, or a Hare's spiral battery. Since, however, it has been found that the constant batteries are the most powerful and unvarying in their results, these have supplanted the other sorts, and the current generated by a battery of two Groves' platinum or Bunsen's carbon cells (§ 505.), with an effective surface of from ten to twenty square inches, will be found sufficient to perform all experiments of this class.

In performing these experiments, it is frequently desirable to reverse the direction of the current without being obliged to change the arrangement of the conductors from the poles. This end is attained by means of a very serviceable piece of apparatus included in the circuit between the battery and the electro-magnetic apparatus; the name of *Commutator*, or *Gyrotrope*, has been given to this instrument: the first idea was conceived by Ampère, who has contributed so greatly to the advance of this department of science: since its first invention, the instrument has been considerably modified, according to the particular object to which it is to be applied. Pohl's is one of the most convenient: of it we have given a vertical, a sectional, and two perspective views in the *figs.* following, 203 *a*, 203 *d*. Four small copper columns, *Commutator or Gyrotrope.*

Fig. 203 *a.*

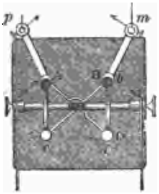


Fig. 203 *b.*

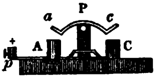


Fig. 203 *c.*

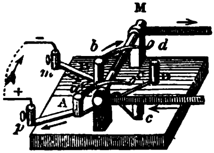
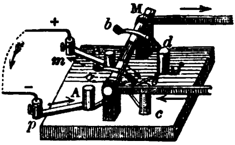


Fig. 203 *d.*



A, B, C, D, about ¼ of an inch thick, are set in a square board; of these A is connected with D, and B with C, by a strip of copper. One of them, A D for instance, is so curved, that when they cross each other no metallic contact may happen. P M is a copper axle, running in two uprights of the same metal, divided in the middle by a piece of wood or ivory, so as to form two insulated portions. On each of these halves is a copper bow, *a c*, *b d*, its shape is best shown by *a* P *c*, *fig.* 203 *b*. The pillars P and M, in which the cylinder turns, serve as binding-screws, by which it can be connected with the electromotive apparatus, *p* and *m* turn about A and B: these arms are also furnished with binding-screws, which serve to conduct the current to the electro-magnetic apparatus. When these connexions are established, the contact is still broken, so long as the curved pieces, *a c* and *b d*, remain in a horizontal position, as shown in *fig.* 203 *b*; but on depressing them, as represented in *fig.* 203 *c*, the connexion is formed with A and B, the current proceeds from P to A, traversing the conductor of the electro-magnetic apparatus, and passing over B, returns to M: move them to the other side, the curved pieces will then be connected with C and D, as in *fig.* 203 *d*, and the current will go from P over C to B, thence it will traverse the conductor to the electro-magnetic apparatus, and return over A back to D and M. — To ensure that a gyrotrope shall act with certainty, it is important to see that all the parts through which the stream is conducted are perfectly in contact at all their points of connexion. In the arrangement we have just been describing, it is best either to gild the points, or else to insert them in mercury cups.

The action of the electric current, agreeably to the principal law given above, disturbs in various ways the natural equilibrium of a magnetic needle, and with a single exception, which will be noticed by and bye, the *deflection* varies according as the current passes over or below the needle, whereas its *dip* is affected by sending the current at an equal height on one side of the needle. The influence of the current is further exerted on a declination-needle, varying according to the direction of the current, with regard to the normal position of the needle.

The following are the principal cases that are to be met with of the fundamental action of electrical currents: —

1.) If the current pass from the S to the N, *above* the declination-needle, its north pole will be deflected westward, and its south pole eastward: if, on the contrary, the current go in the same direction, *under* the needle, its deflexion is exactly reversed.

2.) Conduct the current in this direction on the east side of a needle, and its north pole will be elevated and the south pole will be depressed towards the earth; send the current on the west side of the needle, and the elevation and depression of the poles will be reversed.

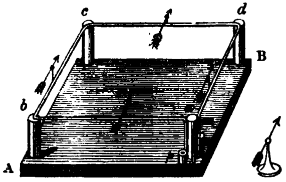
3.) All the above deviations will take place in exactly the opposite direction if the current flow from S to N.

4.) When a current is sent from E. to W., *over* a declination-needle, it will cause the latter to turn completely round, *i. e.* the north pole of the needle will come to the S., and the south pole to the N. If the current be transmitted *under* the needle instead of above it, its poles are not reversed, but the intensity, with which it abides in its original position, is increased.

5.) These circumstances are reversed if the direction of the current be from W. to E.

To verify one by one the different cases of Oersted's fundamental experiment, it is merely necessary to conduct the current from such a battery as we have described, along a copper wire, about one line in thickness, which is to be placed in the prescribed positions, above and below a magnetic needle, moving freely. The different phenomena will then arise, as has been said already. A common variation needle will indeed show the dip, but not quite satisfactorily: to obtain this with any degree of accuracy, it will be necessary to use a balance dipping-needle, such as is depicted in *fig.* 134. To observe simultaneously the various deflexions of the needle, with respect to the different points of the horizon, according as the current is transmitted above or below the needle, some such apparatus as the following will be found convenient: *a, b, c, d, fig.* 204, is a square frame of copper wire, at least a line thick, fastened on four wooden pillars, *a, b, c, d,* in the board A B, but left open at *a*. At this point the ends of the wires are bent downwards at the column *a*, and terminate at *p* and *m* in two binding-screws, which are connected with the corresponding ones of the commutator, *fig.* 203. In the middle of each of the four wires is a steel point, on which a magnetic needle can be placed when the stream of electricity is to be sent under the needles: if it is to pass over them, place them on little stands, *fig.* 204., and put the stands as nearly as possible in the middle of the four sides; care having been first taken that two shall coincide with the magnetic meridian. The phenomena of inclination may be exhibited by this apparatus, if two of these little needles are placed within the frame and near the sides where the current is passing in the direction of the magnetic meridian; or horizontal axes may be placed in the middle of these two sides, and dipping-needles can be slipped on the axes. Do not select as dipping-needles such as are either too large or too strongly magnetized, or else, at the distance they will be asunder, they affect each other, and prevent one another from taking the expected position.

Fig. 204.



To show, in a very simple manner, that, in all cases, the influence of the current is exerted agreeably to the above laws, procure a small jointed doll; extend its left arm, and it will indicate the direction in which the north pole of the needle tends to settle, if the doll be held so that the wire shall be between it and the needle, that its face shall be turned towards the latter, and that the current shall flow from the feet to the head.

§ 547.

It is evident from all that has been advanced in the preceding section as to the influence of the electric current upon magnetic needles, that the former acts upon the latter like a force which exerts itself laterally, and, indeed, at right angles to the line of its direction. If this were the only force in operation on the needle, its axis would necessarily take a position perpendicular to the course of the current. But the magnetic influence of the earth acts upon it at the same time, and imparts to the needle its polar position. From the conflict of these two forces an effect is produced which may be estimated in the same manner as any other compound motion (§ 23.), and by which the different degrees in which the needle is deflected may be accounted for.

The only case in which the position of the needle undergoes no change is when the magnetic current and the "vis directrix" of the earth act in the same direction. The magnetic intensity is then equal to the sum of the two forces. When these forces act in opposite directions the resultant is equal to their difference. The needle is either less powerfully retained in its normal position, or it is completely turned round, when the magnetic intensity exceeds the earth's directing force: in this position of the needle the degree of intensity is measured in like manner (see 4. in the preceding §). When the forces act at any angle whatever, then, by the law of the parallelogram of forces, the needle will acquire the position of their resultant. This is, of course, the case when the current runs parallel to the axis of the magnet (see 1. and 2. in the preceding §).

Hence it is seen why the amount of the needle's deflexion by the passage of an electric current, either above or below it, in a direction parallel to its axis, is invariably dependent on the ratio subsisting between the above-named forces. As a general rule, the greater the intensity of the current, and the less the "vis directrix" of terrestrial magnetism, the greater the deflexion of the needle. If now one of these forces be constant, and we shall be sufficiently near the truth in assuming the earth's magnetic influence to be so at all parts of its surface, then the other force, *i. e.* the intensity of the electric current, may be measured by the angle which the needle is deflected from its normal position. Hence the propriety of using a magnetic needle, both as an index to show the existence of an electric current, and as a measure of its intensity. It is almost needless to remind the reader of its application in the construction of galvanometers (§ 512 and 522).

B. — *Influence of Electric Currents on each other.*

§ 548.

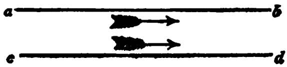
No discovery in natural science excited more general and lively interest than Oersted's. The most distinguished philosophers throughout the world recognised its importance, and endeavoured by repeating and varying his experiments to trace still further this extraordinary property of electricity. They hoped by means of Oersted's fundamental experiments they should be enabled to unravel the mystery in which the connection between electricity and magnetism had hitherto been shrouded. New facts were sought for experimentally which might serve as indisputable evidence of the identity of electricity and magnetism, or from which it might be proved that both were merely modifications of the same fundamental force. Although the object thus earnestly desired has not yet been attained, the active spirit of inquiry that has been called forth has led to important and approximating conclusions. Ampère, who considered Oersted's experiments from a point of view common to them all, selected *the mutual relation of electric currents to each other* for the special subject of his investigations. He was led to the important discovery that, *the electricities in a state of motion*, i. e., *as electric currents*, *act attractively and repulsively on each other according to a certain law*, in a manner resembling the polar attraction (§ 474.) of statical electricity, *i.e.*, of electricity in a state of tension.

By means of his discoveries a connection, which might indeed have been inferred from Oersted's experiments, was clearly shown to subsist between electricity and magnetism. Additional importance attaches to these discoveries, as Ampère deduced from them a highly ingenious theory, in which the phenomena of magnetism were referred to electric currents, or in which, at least, the mutual influence of electricity and magnetism admitted of an easy solution, and in which the various electro-dynamic phenomena were collected into a whole.

§ 549.

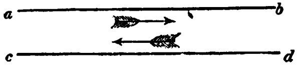
Ampère found that the influence of electric currents on each other varied with their position and direction. The following is the fundamental law according to which these different influences act: —

Fig. 205 a.



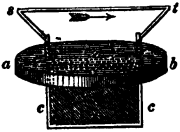
Parallel currents attract each other when they flow in the same direction, as in *fig.* 205 *a.* where *a b*, *c d* are the currents, whose directions are indicated by the arrows. *They repel when their directions are opposite,* as in *fig.* 205 *b.*

Fig. 205 *b.*



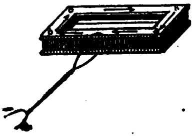
To perform the experiments by which the action of electric currents on each other is illustrated two different pieces of apparatus are required, viz, one fixed conductor, and one which can be moved with great ease. The constructions adopted to effect this object are various; the following are perhaps among the best: —

Fig. 206.



1.) *De la Rive's Floating Current,* fig. 206. — This is the simplest of all moveable conductors. It consists of a disc of cork *a b,* under which is fixed a small Wollaston's battery, composed of a thin plate of copper *c c* (or better still, of platinum), with an amalgamated zinc plate *z.* The pole of the copper element is at +, that of the zinc at —. Small pieces of platinum soldered on to these metals answer best. They should be made to pass through the cork, and a fine piece of silver or copper wire + *s t* — should be connected with them in some simple manner. This electrical float is to be placed in a vessel containing a mixture of water and suphuric acid as the exciting fluid. An electric current will be generated in the direction from *s* to *t,* as shown by the arrow in the *fig.* The second part of this apparatus will be the second electric current, to which the requisite stable position is to be given, with respect to the floating one. A fine copper wire, coated over with silk, is to be carried eight or ten or more times, in the manner of a galvanometer, close together round a wooden frame about six inches long and three inches wide, as shown in *fig.* 207.; from it the ends of the wires, from 1 foot to 1½ in length, are carried to some constant battery: a simple Daniell's, Grove's, or Bunsen's battery is well suited for this purpose. This frame can easily be put in such a position that the current flowing through its longer side may be parallel with the current in the float, or in the same direction with it, or in one opposite to it, when the respective phenomena will follow in each case.

Fig. 207.



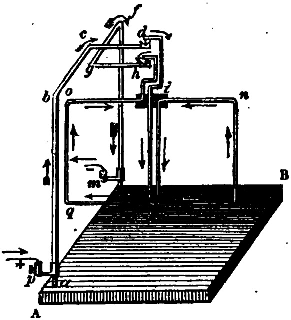


Fig. 208.

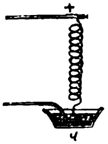
2.) *Ampère's Electro-dynamic Apparatus.* — *Fig.* 208. two stout copper wires *abcd*, *efgh*, stand on the board AB; as the figure shows, they are bent twice at right angles, and terminate at *d* and *h* in two mercury cups; their middle parts will therefore be at right angles to each other. These two bent wires serve partly as fixed conductors of the electric current, but principally as supports of the circulating current. The moveable conductor is bent in the form of a double square *ikln* and *ikqo*; it is insulated at *i* and *k* by insertion in a piece of cork; the ends at *d* and *h* are furnished with steel points; the battery is set in action by placing these points in the mercury cups *d* and *h*. This conductor is completely supported by the upper cup *d*, and turns with perfect freedom upon its steel point. To render the motion as free as possible from friction, it is well that the bottom of the cup *d*, on which the point rests, should be of glass or agate, while the other point is but just immersed in the mercury in the cup *h*. To connect the whole of this apparatus with the hydro-electric battery, two little arms slide on the wire at *a* and *e*, carrying binding-screws at their extremities. The apparatus may either be immediately connected with the poles of the battery at *p* and *m*, or a gyrotrope may be used to effect this object.

Now if the current run in the direction indicated in the figure by the arrows, the part *o q* of the moveable conductor will be attracted by the part *a b* of the fixed conductor in which the current has a direction parallel to that of the former, but it will be repelled by the part *f e* where the current runs in an opposite direction.

To perform another experiment which also depends on the above law of the attraction of currents flowing parallel to each other and in the same direction, we may make use of,

3.) *Roget's oscillating electrical spiral.* — *Fig.* 209. A spiral + —, not coiled very closely, of thin copper wire, such that it may easily be compressed or elongated, is hung vertically with its upper end through the conductor which

Fig. 209.



projects from one pole of the battery, while the point of its lower extremity just touches the surface *q* of some quicksilver which is connected with the other pole of the same battery. On establishing the connection the spiral vibrates longitudinally, because with every contraction of the coils composing the helix, the connection is broken, the weight of the wire then causes its lower end again to sink into the mercury and the action of the battery is restored.

§ 550.

If electrical currents do not run parallel to each other, they display a tendency to move towards the same line and to the same direction on that line. This is shown in the following cases —

Let two rectilinear currents *a b*, *c d*, *fig* 210 *a.* and *b.* form any angle whatever, then they must either attract or repel each other. The former will ensue if both currents flow towards, or from the angular point as represented by the arrows in *fig.* 210 *a.*; but if one current run towards the angle, and the other from it, as in *fig.* 210 *b.* then they will repel. In both these cases the tendency above spoken of is seen in operation.

Fig. 210 *a.*

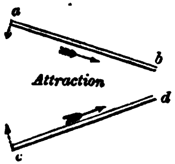


Fig. 210 *b.*

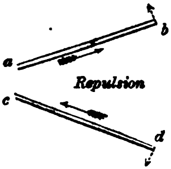
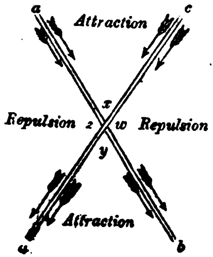


Fig. 211.



If two rectilinear currents *a b*, *c d*, *fig.* 211. cross each other, then by the preceding case they will attract each other between the vertical angles *x* and *y*, and repel between *z* and *w*. The result will be that both conductors will endeavour to take up a position in which the currents that flow through them may have a similar direction.

Expt. To verify the correctness of this assertion, use the floating current described in the preceding section and represented in *fig.* 206. and bring to it the fixed current *fig.* 207. to which such a direction is to be given that it may answer to the several cases given above.

If, however, the reader prefers using Ampère's apparatus, hang in its cup the conductor *i k l n o*, *fig.* 212. and bring the stable conductor so near to the under side of the rectangle *k l* that the direction of its current may make an angle with *k l*. The conductor represented in *fig.* 207. will do, or that one of stout copper wire represented by *q r s t u* in *figs.* 212. and 212 *a.* through which the stream takes its course in the direction pointed out by the arrows, this conductor being used as shown in both the figures to connect the battery and set it in action.

Fig. 212.

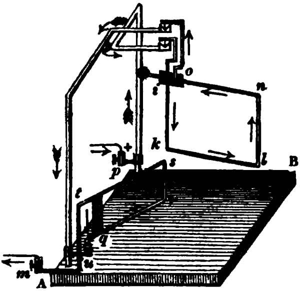
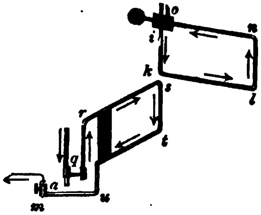
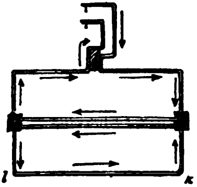


Fig. 212 *a.*



In *fig.* 212. *k l* and *s t* will be attracted: in *fig.* 212 *a.* they will be repelled.

Fig. 213.



To test, by means of this apparatus, the influence which cross currents exert on each other, it will be necessary to suspend the moveable conductor, *fig.* 213. in the mercury cup and to place under the lower part of its current *k l* either the conductor *fig.* 207. or one of the conductors *t s* or *r s fig.* 212. in such a manner that the directions of the two currents may cross each other.

Fig. 214 *a.*

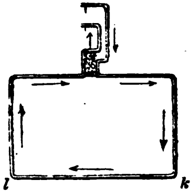
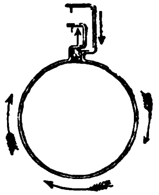


Fig. 214 *b.*



In like manner if the circular conductor *fig.* 214. be suspended in the cup it will acquire such a position that the current flowing in the lower part of the ring may move in a direction equal and parallel to that of the current placed under it.

In performing the last experiment a simple piece of apparatus may be used of which a sectional view is given in *fig.* 215 *a.* and a horizontal one in *fig.* 215 *b.*

Fig. 215 *a.*

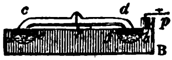
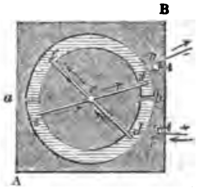


Fig. 215 *b.*

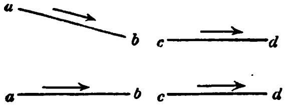


In the wooden disc AB is a circular trough divided at two opposite points by the insulating partitions *a* and *b*, it is consequently divided into two semicircles. In the centre *r* of the trough there stands an upright steel point, on which a copper needle *c d* runs, with an agate cup; the ends of the needle which are of steel, are bent downwards so as to enter the mercury with which the trough is filled. Under this needle is a second *e f*, whose ends are also turned down to reach the mercury, and which can be moved round by the hand. The current runs from the binding-screw *p* into one trough, thence through the two needles into the other, and returns from *m* to the battery. When the needles are in the position given in *fig.* 215 *a.* repulsion obtains; when their position is that represented in *fig.* 215 *b.* attraction ensues so soon as the angle *e r d* is diminished by turning round the wire *e f* which conducts the current.

§ 551.

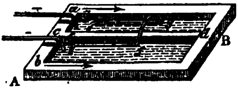
Two currents following each other in the same direction, as also the different parts of the same current, repel each other. That this effect must necessarily arise follows from the phenomena explained in the preceding section; for so soon as the angle between the currents *a b* and *c d* *fig.* 216. becomes very obtuse, *b* and *c* repel just as if *a b* and *c d* were in the same straight line.

Fig. 216.



Expt. Ampère has endeavoured to verify this particular case experimentally by means of the apparatus represented in *fig.* 217. It consists of a long rectangular box AB, divided by a non-conducting partition *c d* lengthwise into two parallel cells. To render the insulation perfect it is advisable to wash these compartments over with a thick solution of shell-lac. Connect one of them *a* with the positive, and the other *b* with the negative pole of a common battery; place a copper wire covered over with silk *e f g h* on the mercury as a circulating conductor, this wire must be so bent that it may reach from one cell over into the other: its two horizontal arms will therefore run one in each of the cells parallel to the partition, the ends of these arms are slightly bent downwards, and thus the battery is set in action. At the moment when the circuit is completed, the floating conductor may be seen to move forward on the surface of the quicksilver from the poles *a* and *b*.

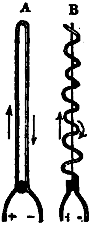
Fig. 217.



§ 552.

If two fixed currents of equal intensities flow close together and parallel to each other but in opposite directions, as in *fig.* 218 A. then their combined influence on a current moving freely is *nil*, that is, they exactly neutralize each other. The same happens when one current circulates round the other in the manner represented in *fig.* 218. B.

Fig. 218.

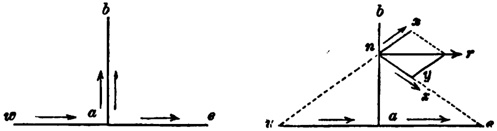


Expt. The truth of the preceding remarks may be tested by sending a current along copper wires, bent in the form shown in *fig.* 218. A and B, taking care in bending the wire that no two parts of it shall touch; then send a current through a moveable conductor, and place the two so that one or other of the above-named actions may be exerted on the free current. It will be seen that the action of the latter continues unaltered.

§ 553.

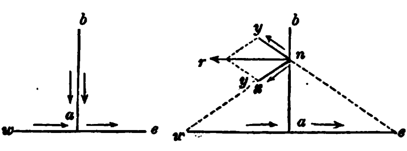
If a moveable electric current, *a*, *b* (*fig.* 219 *a.* and *b.*), flow in a direction at right angles to another which is fixed *w e*, then

Fig. 219 *a.*



the latter will act attractively on one side of *a b* (by § 550.), and repulsively on the other. If the current, *a b* flow from *w e*, as in *fig.* 219 *a.*, then its force will be exerted from *w* and *e* on the point *n* of the moveable conductor, as shown by the arrows *n x* and *n y*. These forces will give *n r* as their resultant, whence the current *a b* will manifest a tendency to move in the direction of the fixed current. If, on the other hand, the moveable current, *a b* flow towards the fixed one *w e*, as in *fig.* 219 *b.* then the

Fig. 219 *b.*



resultant *n r* will have an opposite direction, and the free current *a b* will show a tendency to move in a direction opposite to that of the stable current.

On this law of attraction and repulsion the rotatory motion of such currents about each other depends. For instance, if the current *w e* (*fig.* 220 *a.*) be a horizontal circular current, then

Fig. 220 *a.*

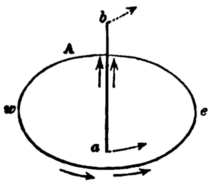
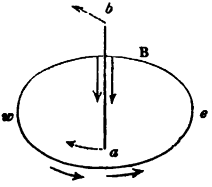
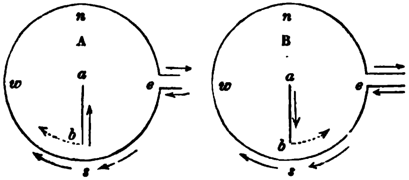


Fig. 220 *b.*



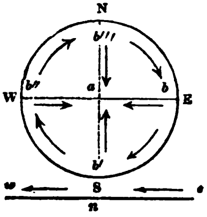
the free current *a b*, which flows out from it, will revolve in the same direction with *w e;* but if *b a* flow towards *w e*, as in *fig.* 220 *b.* then the direction of its current will be opposite to that of *w e*. Again, if *a b* (*fig.* 221.), be a rectilinear current,

Fig. 221.



capable o. revolving about the centre of the circular current, *e s w n*, then its rotation will be in the direction of the circular current, when the current *a b* runs from the circumference towards the centre, as it does in *fig.* 221. A ; but if it be transmitted from the centre towards the circumference, as *a b* (*fig.* 221. B), then it will revolve in a direction opposite to that of the circular current. In like manner, but in a lower degree, there will be a rotation of the current, *a b* (*fig.* 222.), if a rectilinear current E. W., be transmitted near to it. *a b* will in this case run, as is indicated by the arrows, in a direction parallel and similar to E. W., the currents will therefore attract each other, and *b* will be carried to b', on arriving at this point, ab' is repelled by E. N. and is attracted by N. W.; the free conductor ab' will consequently move on to b''; when it has reached

Fig. 222.

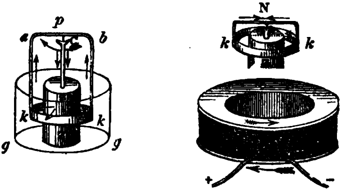


this point, repulsion ensues between the parallel and contrary currents $b'' a$ and E. W.; on arriving at b''' it is again attracted by E. N., and thus the current $a b$ is maintained in a constant state of rotation. If the stable unlimited current E. W. run from E. to W., and the free current be to the N. of the other, then, as the curved arrow in *fig.* 222. shows, it will turn about a in the direction from the E. through the S. to the W. and so on, like the hands of a watch.

There is a great variety in the apparatus which has been constructed to give this rotatory movement to a moveable conductor by means of an unlimited rectilinear or circular current: we shall now proceed to describe only a few of the best and simplest specimens.

First Expt. Rotation of a vertical current about a horizontal circular current.—*Fig.* 223. represents Pineau's simple apparatus. It consists of an amalgamated zinc cylinder Z Z, on which is soldered a stem Z C of copper wire, carrying on its summit a small mercury cup C. The base of the cup should be of agate to diminish friction; on it rests a thin copper wire *k a b k*, supported by a steel point *p*, this frame carries a copper zone. The zinc cylinder with this rotating conductor is placed in a glass of water and sulphuric acid. The whole, thus arranged, constitutes a simple hydro-electric battery, in which the current is transmitted from the zinc cylinder through the liquid conductor to the ring of copper, thence to the two arms of the bent copper frame, as shown by the arrows, and passing through the steel point *p*, it returns again into the zinc cylinder.

Fig. 223.



Now lay on the upper edge of the glass the coil M, which is made to fit it exactly; join its ends (+ —) with the poles of a constant battery, and the current which ascends vertically will revolve in the same direction as the current that passes through the coils of wire.

Substitute a copper cylinder for the zinc one Z, and an amalgamated zinc ring for the copper one; the current will flow down the arms *a k*, *b k*, and the direction in which the apparatus revolves will be reversed.

Second Expt. Rotation of a moveable horizontal current about the centre of a circular current. — The apparatus described in the preceding experiment will do to perform this also; the only alteration required will be to give the zinc or copper cylinder but a very short conducting-wire, so that the current may radiate horizontally either from or to the coil of wire; this is shown by the arrows in *fig.* 223. N; the direction in which the rotation will happen depends on whether the current flows from or to the coil.

If it is wished to excite in the moveable conductor a more powerful and lasting current than the simple battery we have just described is capable of generating, then combine the apparatus on the principle of a Daniell's or a Grove's constant battery, by separating the electro-motive metals by means of a porous earthenware cell, which should be inserted in the glass vessel, and then add the appropriate liquids to act upon the metals.

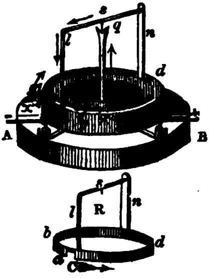
Third Expt. Rotation of the fluid conductor about a circular current. — The fluid conductor may be made to take the place of the solid, *i. e.*, if we have no metallic conductor such as was described in the preceding experiments, then the liquid itself will begin to revolve. The same apparatus will do in this case also, only substituting for the moveable copper ring (*fig.* 223.) an open cylinder of the same metal, which fits into the glass vessel. Fill it with any suitable fluid (a mixture of liquid sal ammonia and muriatic acid is what Fechner recommends; and to increase still more the intensity of the current, a solution of sal ammonia may be allowed to dry on the copper cylinder) and the current will pass from the zinc cylinder to the copper ring, *i. e.*, it will radiate from the centre to the circumference. Now surround the glass with the coil of wire M, whose ends are to be connected with the poles of a simple battery; on connecting the battery the fluid will revolve agreeably to the laws with which we are already acquainted. Its rotation will be still more evidently shown by placing small floating bodies on the surface of the liquid.

Fourth Expt. Rotation of a horizontal current by the action of a current of unlimited length. — This phenomenon is observable on bringing any rectilinear conductor, *e. g.*, one side of the galvanometer frame (*fig.* 207.) to the horizontal current of the second experiment.

Fifth Expt. Rotation of a circular current by the action of a radiant horizontal current. — This is Savart's interesting inversion of the second experiment, in which the circular current of the multiplying coil is entirely dispensed with.

Fig. 224. represents the apparatus: c c is a cylindrical vessel of copper or brass, whose bottom is coated over with some varnish to insulate it, and which stands in a cavity turned in the wooden stand A B. In the centre *r* of this board stands a vertical copper stem, furnished at top with a quicksilver cup *q;* from *r* goes a strip of copper let into the wood and terminating at *p* in a binding-screw; on the outer side of the copper vessel there is also a similar binding-screw *m*. The moveable conductor consists of a fine strip of copper *a b d* c, open between *a* c, where it is joined by inserting some bad conductor, such as a piece of horn. The strip *n*, likewise in the copper framework *l s n*, consists of some bad conductor; the ring turns about the axis *q r* on the point *s*, which works in the cup *q*. To set the apparatus in action pour sulphuric acid and water as the conducting medium, into the cylindrical vessel, connect the screws *p* and *m* with the poles of a simple constant battery. Now, when the current is generated at *p*, as indicated by the arrows in the *fig.*, it ascends the column *r q*, descends the leg *l* of the frame, and runs round the copper band in the direction from *a* to *b* to *d* to c. But streams are emitted from all points of the band, as *a x*, c *y*, in a radiating direction, through the fluid conductor to the circumference of the brass. These partial currents in the fluid may be considered as stable with regard to the moveable copper ring, which in this case will rotate in the direction *a b d* c, like the band of a watch. To give to it the opposite course, the arm *l* of the frame must be fastened at c to the rim of copper, as shown in the *fig.* R.

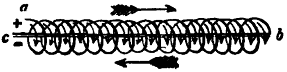
Fig. 224.



§ 554.

If we conceive of a wire being coiled round as a helix, see *fig.* 225., and that within this spiral the wire is carried back again in a right line, we shall have to distinguish a threefold direction as taken by the electric current which traverses it. For instance, if the current enter at *a*, it will turn repeatedly in a circular manner about the right line *c b*, as it

Fig. 225.



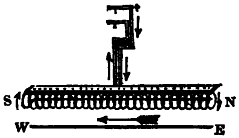
advances from *a* to *b*; on arriving at *b* it returns inside the spiral from *b* to *c* along the straight part of the conducting wire. The effect of the current in the direction from *a* to *b* will necessarily be compensated by its return from *b* to *c* (see this case more at length in § *552.*), so that only that effect will remain which it acquires in revolving about *c b*. A linear series of such circular currents, which may be considered as being at right angles to the axis *c b* of the spiral conductor, is called an *electro-dynamical screw*, an *electro-dynamical cylinder*, or, according to Ampère, a *solenoid.*

> For brevity's sake, as well as for the other applications of these spirals, by the end S. will always be meant the *South* Pole, when the circular current runs from left to right or in the same direction as the hand of a clock; and the other N., in which the circular current flows in the opposite way, *i.e.*, from right to left, will stand for the *North* Pole.

If a solenoid move freely in a horizontal plane, and a rectilinear current be transmitted either above or below it in the direction of its axis, then, by § *550.* it will take such a position that those portions of its own horizontal current which are nearest to the rectilinear one, may take the same direction as the latter. Accordingly, if the solenoid be so placed that its axis S. N. lies in the magnetic meridian, it will be seen that if a rectilinear conductor be put into those different positions above or below it, into which it might be set with regard to the polar direction of a variation needle, the deflections will answer exactly to those of a magnetic needle thus acted on. (See § *546.*)

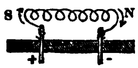
First Expt. Hang the solenoid *fig.* 226. in an Ampère's frame and conduct a current through it, whilst either the same current or another traverses the rectilinear conductor E W placed beneath it; then whatever the position of the latter, the axis S. N. of the former will always be at right angles to E. W.; so that the horizontal currents in the lower part of S. N. flow in the same direction as the current in E. W.

Fig. 226.



Second Expt. Connect the small electro-dynamic spiral *fig.* 227. with a De la Rive's float, and set it on some strongly acidulated liquid; conduct a current above it in the direction of its axis, and the spiral will revolve so as to take with regard to the rectilinear current the position laid down in the law.

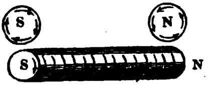
Fig. 227.



To render still more intelligible what

has been said in the preceding paragraphs, as indeed what will be advanced in the next Chapter too, the student may perhaps find it useful to mark on two wooden cylinders the direction of the circular currents, as it is done in *fig*. 228. by the arrows.

Fig. 228.



C. *Influence of Magnets on Electric Currents.*

§ 555.

As an electric current deflects the needle from its polar position, so does a magnet deflect a moveable conductor through which a current flows. If we imagine the magnet to be fixed and the current rotatory and situated between the magnet and the observer, *it will always take with respect to the axis of the magnet such a rectangular position that its north pole will lie to the left of the line expressing the direction of the current.*

The different positions which the direction of the current can occupy with respect to the axis of the magnet, are the following: —

1.) If the current go from north to south, or inversely *below* the axis of the magnet, then in either case it will so place itself as to flow from E. to W.

2.) But, if the current flow from S. to N., or inversely *above* the axis of the magnet, the direction of the current will always be from W. to E.

3.) If a current flow from E. to W. under a bar magnet lying in the magnetic meridian, its position will not be altered by the magnet; but if it flow from W. to E. it will be turned round by the magnet, so as to come into the direction from E. to W. The converse phenomena obtain if the current be transmitted *above* the magnet.

First Expt. To exhibit the motions of a current flowing under a bar magnet the simplest way is to use the floating current represented in *fig*. 206., and place over it a powerful bar-magnet, or one leg of a horse-shoe magnet, in the various positions named above.

Second Expt. To generate the movements in a current situated above a bar magnet, it will be best to suspend the conductor in an Ampère's frame, *fig*. 213., and then to place the magnet under it.

§ 556.

The very same effects are obtained if a solenoid be used instead of a bar magnet: hence it appears that the moveable current always takes that position in which its direction is the same as that of the circular current in the spiral which is turned towards it.

Bring a magnet near to a moveable electro-dynamic spiral, and the latter will be acted on just like a declination needle; for the magnet will attract unlike poles of the spiral, and repel like poles.

> *Expt.* This may be verified either by bringing the poles of a magnet near to the floating solenoid, *fig.* 227. or to a solenoid suspended in Ampère's frame.
>
> The wooden cylinders described at the end of § 554. will assist the reader to comprehend the above remarks more easily.

§ 557.

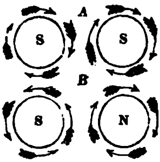
Ampère, reasoning from the phenomena of the mutual action of magnets and of electric currents, has framed his important hypothesis to which we referred very briefly in § 548. It is this, that *every electro-dynamic spiral may be regarded as a magnet, and every magnet in the exertion of its influence resembles such a spiral;* i. e., *it is like a body about whose axis electrical currents turn in planes perpendicular to the axis, or at least in planes very nearly perpendicular to it, and that on these electric currents all the so called magnetic influences depend.*

If a magnet be placed in its polar position, *i. e.*, with its north pole towards the N., and its south pole towards the S., these currents must necessarily go on the upper side from W. to E., downwards on the eastern side, on the under side from E. to W., and upwards on the western side; in fine, the currents round magnets must be assumed to be opposite to the apparent daily path of the sun round the earth, if the action of electric currents on them is to answer to the law which regulates the action of the latter on each other.

According to this hypothesis, all the mutual action of magnets and electric currents (Oersted's fundamental experiments, § 546. and the phenomena described in the preceding sections) are explicable, according to Ampère's law of the influence of electric currents on each other (§§ 549.—553.); in like manner we can satisfactorily explain why the similar poles of two contiguous magnets should repel each other, and why dissimilar should attract. Let the two circles, *fig.* 229. A, represent the south poles of two contiguous magnets, and it is clear that the electric currents, which are supposed to exist in the magnets, flow in contrary directions at the sides where the poles are next each other, they therefore are repulsive, § 549. But if a north pole be next to a south pole, as in *fig.* 229, B, then it is obvious that at the contiguous poles the currents flow in the same direction, and that they consequently attract each other.

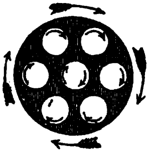
This is seen if the poles of two magnets, or, better still, if the ends of the wooden cylinders already mentioned, be placed together.

Fig. 229.



We must remark that in the explanation just given, whatever the body we consider as a magnet, the result of its action can only be exerted externally. Since, however, every magnet shows a similar energy, even in its smallest particle, and as every portion of it is a bipolar magnet (§ 437.), it has been further assumed that even the minutest particles of such a body are equally surrounded by an electric current, which completely encircling it returns into itself. According to this theory, we may imagine a transverse vertical section of a magnet to be represented in *fig.* 230. The elementary currents of each magnetic molecule, as represented in the small circles contained in the section, will form one circle, which equally embraces the outer surface, and is, in fact, the resultant of all the forces; such a combined action may therefore be considered as a system of parallel currents, such as is represented in *fig.* 228.

Fig. 230.



This extremely ingenious theory, which accounts in so easy a manner for all magnetic and electro-magnetic phenomena, is not, after all, quite free from objection, as the permanence of electrical currents in magnets, which is a postulate required by the theory, is not reconcilable with the general relations of conductors of electricity, to which class of substances those metals belong which are capable of being magnetized: and again, we are acquainted with no instance of the independent permanence of these currents apart from electro-motive influence. Hence many philosophers reject this theory as to the nature of magnetism, especially as there are so many phenomena which seem to favour the existence of separate magnetic fluids, and which therefore admit of no satisfactory solution according to this recent hypothesis.

§ 558.

We know, by § 553. under what circumstances a finite mobile conductor will be put into a state of progressive or rotary motion, by the action of a stable and unlimited current, or of a circular current, upon it. Since now, by Ampère's theory every magnet is a body surrounded by electric currents, it follows, if his hypothesis be correct, that similar movements will ensue from the mutual action of electric currents and magnets on each other, and in fact under the circumstances named above, the corresponding movements do take place, both when a moveable conductor is acted on by a fixed magnet, and when a moveable magnet is acted on by the current which passes through a fixed conductor.

Out of a great number of experiments of this class, we shall select only a few of the most interesting, from which it will be seen how far Ampère's hypothesis supplies a complete and satisfactory explanation of all the different electro-magnetic phenomena.

First Expt. Attractive and repulsive influence of a magnet on a conductor moving freely. — According to Ampère's theory, a rectilinear conductor will be attracted by a magnet if the current flow in the same direction as the hypothetical current in that side of the magnet which is nearest to it; but repulsion ensues if the moveable current have the opposite direction.

If the moveable conductor be circular, it will be attracted by the pole of the magnet, which is made to approach it, if the current supposed to exist in the latter move in the same direction; but if it move in the contrary direction, it will be repelled.

De la Rive's floating currents are best adapted to verify this. — Bring the N. pole of a magnet near the current *s t*, *fig.* 206. when this flows from left to right, so that the current may pass over it, and it will flow towards the S. pole of the magnet; if the S. pole be presented to it in like manner, the current will be repelled. — These movements will be exactly reversed if the magnet be held over the conductor so that the current may intersect the magnetic axis at right angles.

Fig. 231 *a.*

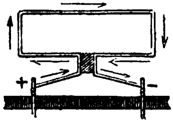
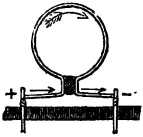


Fig. 231 *b.*

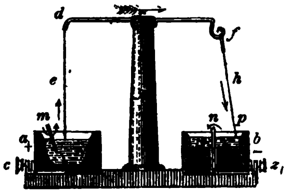


Connect the circular conductor, *fig.* 231. with the hydro-electric float, *fig.*

206. and if the position and course of the currents be as is represented in the diagram, it will be attracted in the same manner as the rectilinear conductor, when the N. pole of the magnet is presented to it, and it will be repelled when the S. pole is brought near.

Second Expt. Faraday's Rotatory Apparatus for a vertical current about the pole of a fixed magnet, and for the pole of a magnet about a fixed vertical current. — *Fig.* 232. gives a vertical section of this apparatus. A sufficiently stout copper wire *d f* is fastened on the upright column of wood *g*. From the end *f*, which terminates in a hook, there hangs a fine platinum wire, whose lower end reaches the trough *b* of mercury; this wire is suspended by a noose, so that it has perfectly free motion; the platinum wire *e*, on the contrary, is soldered to *d*, and descends vertically to the wooden cup *a* of mercury. In the centre of the vessel *b* is the vertical bar-magnet *n*, a magnetized sewing-needle will answer the purpose, fastened into a copper tube, which goes through the bottom of the vessel. A small glass bead *p* is fixed to the end of the wire *h*, that it may not come in contact with the magnet. At the bottom of the cup *a* is a magnetized sewing-needle *m*, attached by a fine thread of platinum, but still with room to play; by means of a small spiral of platinum wire, which can be pushed on to it, this needle may be made to swim vertically in the mercury. The apparatus is connected with the poles of a constant battery by the binding-screws *c* and *z*, from which copper wires run so as to connect them with the two cups *a* and *b*. When the battery is thus set in action, the current circulates through the conductors as represented in the *fig.* by the arrows, and the north poles of both the magnets are turned upwards; the moveable conductor *h* therefore revolves about the pole *n* of that magnet in the same direction as the hands of a watch, whilst the pole of the magnet *m* turns in a contrary direction around the fixed conductor *e*. — Reverse the direction of the current, or place the S. poles of the magnets uppermost instead of their N. poles, and the rotations will be inverted also.

Fig. 232.



Third Expt. Rotation of a magnet about its own axis. — *Fig.* 233. represents a simple apparatus by which to perform this experiment. It consists of a glass tube *a b* about three inches long and one inch wide. Its lower end is closed with a cork, through which an iron wire passes, projecting slightly beyond the cork, and terminating in the point *e*. The lower end of this wire is soldered into a copper plate which is connected with the binding-screw *z*. In the upper end of the tube is inserted a copper ring *b d*, which is connected from *d* externally with the other binding-screw. The glass tube is then filled with mercury up to the ring, and the little bar-magnet *s n*, rounded off at both ends, is immersed in it till it touches the iron pin *e*. One half of the magnet will therefore rise above the level of the mercury, in which, as it touches the iron at a single point, it will have a perfectly free motion around its own axis. Next connect the binding-screws with the poles of a powerful constant battery, and the magnet will begin to turn about its axis. — If the current proceed, as it is represented in the figure, from the copper ring *d b* to the magnet, its rotation will follow in the direction of the electric currents which surround it. Reverse the direction of the current, so that it may proceed from the magnet to the copper ring, and the magnet will turn in the contrary direction to the currents which encircle it. From Ampère's law about the action of electric currents on each other (§ 533.), we should have inferred that these must be the directions taken. See also *figs.* 233 *a.* and *b.*

Fig. 233.

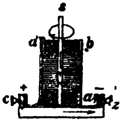


Fig. 233 *a.*

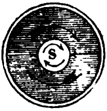


Fig. 233 *b.*

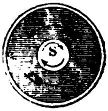
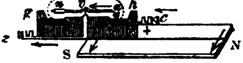
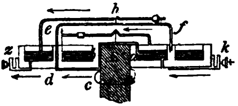


Fig. 234.



Fourth Expt. Schweigger's rotatory apparatus, in which horizontal currents sent through the pole of a magnet impart to it a circular motion. — In *fig.* 234. *g h* is a section of a wooden plane in which a circular trough *t t* is cut to contain quicksilver. Through the centre of the plate the copper wire *w* passes, the extremity of which is furnished with a steel point. On this point a copper needle *n a* rests, its length is about four inches, and in the middle it is furnished with a cap *v*: one end of the needle, which is of platinum, is so bent as to be immersed in the mercury; as a counterpoise, a little weight *n* is attached to the other end of the needle. Connect the screw *c*, which communicates with the mercury, with the positive pole of a constant battery, and the screw *z*, which communicates with the copper wire *w*, with its negative pole; on establishing contact, the current will flow from *a* to *v* through the needle. Slip a bar magnet S. N. under the plate above which the moveable conductor turns, and if S. be the magnet's south pole, *n a* will turn from E. through S. to W. and N. Place the north pole of the magnet under the conductor, and its direction will be reversed; *i. e.*, an opposite direction will be imparted to the current.

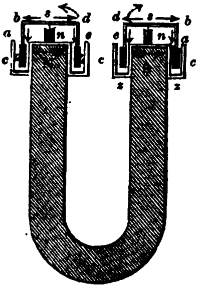
Fig. 235.



Two needles which are traversed in an opposite direction by a current, if acted on by the same pole of a magnet, revolve in contrary directions. *Fig.* 235. is an apparatus for showing this: *a b* is a section of a circular plate of wood, having a hole drilled through the middle, in order to thrust the pole of a magnet through. Concentric with this hole are two grooves, intended to hold mercury, or some acidulated fluid. Two light copper needles are balanced, in the same manner as has been dedescribed in the preceding experiment, above the centre of these grooves on the steel point of the copper wire *a b c d e f*. The ends of these needles are capped with platinum points, which are immersed in the fluids contained in the grooves. Now connect the two screws *k* and *z* with the poles of a hydro-electric battery; if the current enter at *k*, it will traverse the whole length of the wires in the direction shown by the arrows. Compare this direction with that in which the hypothetical current is supposed to go round the S. pole of the magnet, and it will readily be seen from the law so repeatedly referred to, in what way each of the needles must turn, and that they will revolve in exactly opposite directions. — A change in the direction of the current, or a substitution of the north pole of the magnet for the south, will reverse the rotation of the needles.

Fifth Expt. Ampère's apparatus to effect the rotation of the electromotors of a simple hydro-electric battery about the axis of a magnet. — On the two poles of a horse-shoe magnet, *fig.* 236., place two cylindrical copper vessels. Place the steel point of an amalgamated zinc ring (like that given on a larger scale in *fig.* 223. N.), on which is soldered a light copper handle into the cup *n*, which is connected with the copper bucket. Into this bucket pour a mixture of 1 part sulphuric acid to 4 or 6 of water, and the current will pass in this simple battery from the copper cylinder to the zinc ring; for it will run from its point of rotation *s*, in the horizontal part of the copper handle which acts as a conductor, eccentrically to *d* and *b*; thence it descends in the parts of the conductor parallel to the axis, whence it returns from the zinc ring through the conducting fluid to the copper, whilst the currents which circulate about the poles of the magnet, flow horizontally. The moveable conductor revolves, therefore, about the N. pole from E. through N. to W.; that about the S. pole from W. through N. to E. They, therefore, turn in directions opposite to each other and to the currents of the magnet.

Fig. 236.

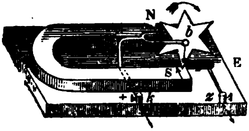


Instead of the copper vessel use a similar one of zinc and for the moveable zinc ring substitute one of copper, one of thin platinum will do better still, and the current will ascend those parts of the conductor, or handle of the bucket, which are parallel to the axis of the magnet and the rotation will take place in the same direction as that in which the currents flow around the magnet.

If the cylindrical vessels be large enough when laid on the pole of the magnet to move freely round it, and if they also are made to rest on the poles upon steel points, they will revolve too, that is, if the magnet be a sufficiently powerful one; and for reasons with which we are already well acquainted, their rotation will be contrary to that of the rings.

Sixth Expt. Barlow's rotating wheel between the poles of a horse-shoe magnet.— A light wheel of thin copper notched like a star, runs on an axis terminating in points which rests in the sockets of a fork *a b* of copper wire, the wheel may be about 3 or 3½ inches in diameter. Under the wheel is a groove *q* in the

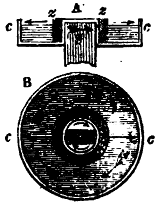
Fig. 237.



board W. E., into which so much quicksilver is to be poured that the points of the wheel may just touch it: *c* and *z* are binding-screws, the former connected with the forked conductor and the latter with the mercury. Connect the apparatus with the poles of a powerful constant battery, the current will be carried through the wheel which will begin to revolve as soon as the poles of a large horse-shoe magnet are placed near it in either a horizontal or a vertical position, so that the wheel shall stand between the arms of the magnet. The direction in which the wheel turns depends, according to the law already referred to so often, on whether the current in running from the centre of the wheel to its circumference, or conversely, follows the direction of the currents that encircle the pole of the magnet, or not. If the wheel stand, as is assumed in *fig.* 237., E. and W. the arms of the magnet will have the same position too, and the N. pole of the magnet will lie N. of the wheel, and the S. pole S.; if the current enter at *c*, it will advance, as the arrow shows, along the fork to the wheel, from the centre of which it passes to the mercury, and from the direction of the magnetic currents it is clear, that with this arrangement of the apparatus, the wheel will turn in the same way as the hand of a clock. We may easily determine in what direction the wheel will revolve if the direction of the current, or the position of the poles of the magnet, be reversed; it will much facilitate the calculation if the direction of the current be marked on the poles of the magnet, or if a wooden model of a magnet be constructed, and the hypothetical currents are marked upon it, in the same manner as on the wooden cylinders described in § 554. and represented in *fig.* 228.

Seventh Expt. Rotation of the fluid conductor of a simple battery about the poles of a magnet. — The fluid conductor of a simple battery may be made to circulate by either pole of a magnet, in the same manner as by a circular current (see *Third Expt.*, § 553.). *Fig.* 238. represents Fechner's apparatus by which to perform this experiment, A being a vertical section and B a bird's eye view of it. *c z z c* is a circular copper vessel, over its inner cylinder which fits on the pole of a horse-shoe magnet, is pushed a ring of amalgamated zinc *z z*. Pour into the vessel a mixture of aqueous sal ammonia and acid; the positive electricity will be discharged from the zinc ring through the fluid to the copper, as is shown by the arrows

Fig. 238.

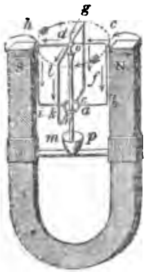


in B; and if the vessel be fitted on the pole of a horse-shoe magnet, the fluid will revolve in the same direction as the hypothetical currents in the pole of the magnet.

Eighth Expt. Rotation of a thermo-electric current between the poles of a magnet. — A thermo-electric current moveable about a vertical axis, if subjected to the influence of the two poles of a horse-shoe magnet, obeys precisely the same laws as a hydro-electric current in its rotation; an additional proof this of the identity of electricity obtained from various sources.

Cumming and Marsh, in verifying the accuracy of this assertion, used the following simple thermo-electric battery: — Two thermo-batteries of a square form, and crossing each other at right angles formed a moveable conductor; the batteries consisted of a combination of platinum and silver wires; *fig.* 239. represents this thermo-electric cross. In each of the rectangles one half *a b c d* and *e f g h* is of platinum, and the other half *d h i k*, *d l m n* of silver. The ends of the wires are soldered at *a*, *e*, *k*, *n*, into a ring of silver wire; in their upper point of intersection *d* is a fine steel wire which rests on the agate cup *o*, at the top of the upright stem *o p*; the whole apparatus can therefore be made to turn with the greatest ease about the vertical axis *d p*. About 2 inches below the ring stands a small cup *p*, containing a little cotton and spirit of wine. The battery thus arranged is to be set between the poles of a powerful horse-shoe magnet, so that the vertical part of the wires shall be about ¼ of an inch from the magnet. Light the spirit, and when the junctions of heterogeneous metals at *a* and *e* become heated, the electric current will run through the two batteries in the direction indicated by the arrows in the *fig.*, and the poles of the magnet acting on it will cause it to revolve. In the position of the poles depicted in the diagram, the thermo-electric current will pass from left to right, *i. e.*, from E. through S. to W.

Fig. 239.



§ 559.

The influence of electrical currents on each other, and the reciprocal action of such currents and magnets on each other, varies with their distances. Biot, Savart, and Schmidt found experimentally, that *the influence of a conductor on a magnetic needle diminishes in the inverse ratio of the distance,* and Laplace proved mathematically that *the force answering to each particular point of the current is inversely as the square of its distance from the magnet.* Now, as in the mutual action of magnets and electrical currents on each other, and in that of currents upon currents, we have invariably found action and re-action to be equal and opposite in all the cases that have as yet come under our notice, we may therefore infer that the law holds good in all cases of the mutual action of these forces; it will be readily seen that this is the same law as that by which the radiant action of the magnetic and electric forces is regulated. (§§ 440. and 475.)

Biot and Savart ascertained the influence of an electric conductor on a magnetic needle to be what is stated above, by allowing it to act on the needle at different distances, and so causing it to oscillate. From the number of oscillations made in equal times they deduced the result just as in the oscillations of a pendulum, and in the determining of the intensity of magnetic forces.

D. *Influence of Terrestrial Magnetism on Electric Currents.*

§ 560.

As we have already shown that electric currents exert a directing influence on magnets having free motion, and that magnets exert a corresponding influence on electric currents having free motion, it was natural to expect that terrestrial magnetism would operate similarly on electric currents. This has actually been proved to be the case, and so far as observation has yet shown, the influence of this force may according to Eisenlohr be expressed in general terms thus: — *Terrestrial magnetism acts on electric currents just as if the entire globe were encircled with electric currents from E. to W. in lines parallel to the equator, the resultant of all these currents being represented by the one current in the magnetic equator.*

The causes have not yet been exactly proved which generate the current whose existence is thus assumed, the direction in which it is supposed to flow is the same as that in which the sun appears to move round the earth, and in which the progressive warming of the earth's surface takes place. Since now it has been proved that electrical currents generated by heat, exert precisely the same influence on magnetized needles as those caused by Voltaism, it has been inferred that the thermal action of the sun is the generating and maintaining cause of these currents. (Compare § 533.)

§ 561.

A rectangular conductor turning freely about a vertical axis will always stand perpendicularly to the magnetic meridian if acted on solely by the earth's magnetism; in this position of the rectangle the current in its under surface will flow from E. to W., *i. e.*, in the same direction as the current of terrestrial magnetism is supposed to flow in; this will be seen to agree with the action of electrical currents on each other as described in §§ 549. and 550.

Expt. A floating conductor bent in the shape of *fig.* 231 *a.* and *b.* will take the position E. and W. if the current excited by the fluid in which its single battery is immersed, be sufficiently powerful to turn round the floating disc of cork.

This position of a moveable conductor is obtained with greatest certainty if a rectangular conductor like *fig.* 214 *a.* or a circular one like *fig.* 214 *b.* be suspended in an Ampère's frame, *fig.* 208., and a powerful current is conducted through it.

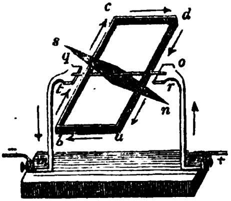
If on the contrary, the form of a double rectangle be given to such a conductor as *fig.* 213. so that the current must move along it in the direction shown by the arrows, then it will not be made to turn in any position by the force of terrestrial magnetism, for the forces neutralize each other both vertically and horizontally; care must of course be taken that the wire is insulated at X, where it crosses. This *astatic conductor*, as it is called, which is one of Ampère's inventions, very much resembles an astatic needle (§ 538.), and is of essential use in the experiments described in §§ 549. and 550., in which the absolute influence of one electric current on another is to be measured.

§ 562.

If a rectangular conductor move freely about an axis passing through the middle of its longer side and through its centre of gravity, and further if this axis of rotation cut the magnetic meridian at right angles, then the conductor, which was at first perpendicular, acquires such a slanting position, that the plane in which the current moves cuts the plane of the needle's dip at the place of observation at right angles (§ 445.). Hence it appears that the part of the current which inclines towards the terrestrial equator flows from E. to W. whilst that which is turned towards the pole runs from W. to E., or in other words, that the current as a whole takes such a position as the current supposed to exist in a dipping-needle has about its axis.

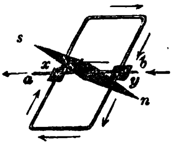
Expt. Such an electrical dipping-needle or inclinatorium, may be constructed thus, according to Eisenlohr *fig.* 240. Procure a light wooden frame, *a b c d* which is provided with two common sewing-needles *o* and *q*, that serve as an axis about which it can turn easily. Wind copper wire covered with silk several times about the frame in the direction *a b c d*, and let one end have a metallic connection with the trunnion *o*, and the other with that at *q*. These trunnions are now to be laid on the bent parts of the metal stems *p r* and *m t*, which are widened out into little stages *r* and *t*, and are highly polished; the centre of gravity of the apparatus is to be so arranged that the frame may take a horizontal position. Now place the whole so that the axis of rotation may stand perpendicularly to the magnetic meridian, and connect the binding-screws *p* and *m*, with the poles of a powerful constant battery, as soon as the current begins to flow through the wire, the frame will take the position represented in the *fig.* To mark the position of the dipping-needle, a cardboard needle *s n* may be fixed in the middle of the frame, so as to intersect the plane of the former at right angles.

Fig. 240.



A similar result will be obtained with a common wire conductor, *fig.* 241. insulated at *x*, and placed with the ends of its axis *a* and *b*, on the stages of *fig.* 240. if a sufficiently powerful current be sent through it.

Fig. 241.



On account of their friction it is sometimes difficult to insure that these moveable conductors shall take their proper position. If the experiment described above does not fully answer, the failure is to be ascribed to the excess of friction, the same remark holds good with regard to several of the preceding experiments.

§ 563.

Every solenoid possessing tolerably free motion and through which a powerful electrical current is sent, will (in consequence of the influence the earth's magnetism exerts upon it) take such a position that the circular currents which run downwards will flow from E. to W., and those on the E. side will run upwards, its north pole will consequently point towards the N. (see § 554.), and its south pole towards the S.

> *Expt.* To show experimentally that a solenoid has a tendency to acquire the polar position just spoken of, and to rest in it, hang one, *fig.* 226., in an Ampère's frame in such a manner that its poles may stand E. and W. When in this position send through it a pretty strong current, it will begin to turn, and, after a few fluctuations, it will settle down in the polar position.
>
> The same result is obtained if the floating solenoid be used, *fig.* 227., only the electric current must be strong enough to overcome the resistance of the fluid to the motion of the apparatus.

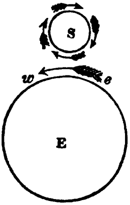
In like manner a solenoid capable of revolving about a horizontal axis passing through its centre of gravity and at right angles to the plane of the magnetic meridian, will necessarily take a position coinciding with that of the dipping-needle, because the whole of the currents circulating in it are at right angles to this direction; they therefore as a whole, coincide with the position which each single current takes. The greatest practical difficulty consists in so constructing a solenoid, that it may have the perfectly free and easy motion that is indispensable to the success of the experiment.

§ 564.

The assumption that electrical currents circulate about the earth is consistent with the directing force they appear to exert on magnetized needles. For since by Ampère's hypothesis a variation needle may be regarded as a solenoid (§ 557.), it will take the same polar position as the latter, when the electrical currents supposed to exist in it acquire a position exactly opposite to that of the currents which flow in the magnetic equator of the earth, *i. e.*, they will flow exactly opposite to each other. This can however be the case only when the north pole of the magnet is turned towards the north pole of the earth, and its south pole to the south pole of the earth.

Let E, *fig*. 242. be a section of the earth through its magnetic equator, and let *e w* be the direction of the current flowing round it from E. to W. Now let S. be the section of a magnet moveable in a horizontal plane above its surface, the latter must take such a position that its circular currents will have the same direction as those on the earth, they will therefore flow from E. to W. This is the case in the northern hemisphere if the south pole of the magnet be turned towards the equator, and in the southern hemisphere if its north pole be turned towards the equator.

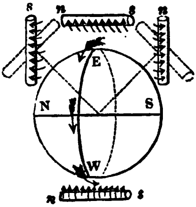
Fig. 242.



But the north pole of a dipping-needle will dip towards the earth in the northern hemisphere, and the south pole in the southern hemisphere, when the currents by which they are encircled flow in the same direction as those of the magnetic equator.

The wooden cylinders already described and represented in *figs*. 228. and 243. may serve to illustrate the true posi-position of the dipping-needle. E. S. W. N. may represent one meridian of the earth; E. W. its magnetic equator, and the arrows on it the direction of the terrestrial current. Then it is easily seen that such a needle, if held horizontally over the equator, *e. g.*, over E. and W., must, in the northern hemisphere, take the position towards N., and in the southern towards S. as shown in the *fig*., for their currents to flow in the same direction as that of the earth itself.

Fig. 243.



Barlow tried experimentally to prove this assumed influence of the current of terrestrial electricity on magnetic needles. He procured a wooden globe, and through every tenth degree he carried a wire, along which he passed an electric current. Then he found that a magnetic needle, so circumstanced as not to be acted on by the earth's magnetism and constructed like a dipping-needle, assumed the same relative positions as such an instrument would have taken for the respective latitudes on the earth.

§ 565.

A rotatory motion may be imparted to an electric current by terrestrial magnetism, if the conditions specified in § 553. are complied with, and if the conductor be so contrived as to turn with extreme readiness. This is the case with a horizontal current revolving about a vertical axis. If the current recede from the axis, the rotation will be from E. through the N. to the W.; but if towards the axis, then its rotation will be in the opposite direction.

Expt. If the needle which turns horizontally in Schweigger's rotating apparatus, *fig.* 234 *a.*, be light enough, and if it turn easily enough, the influence of terrestrial magnetism alone will cause it to revolve.

E. *Excitation of Magnetism by Electric Currents.*

§ 566.

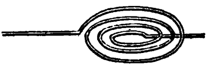
Besides the deflecting influence exerted by the electric current on magnetic needles, it possesses the further property of imparting both transient and permanent magnetism to different conductors of electricity.

Arago first made this observation shortly after Oersted's splendid discovery. He found that every metallic conductor, so long as an electric current flowed through it, attracted towards itself iron filings and other similar bodies in the same manner as the poles of a magnet. This attractive energy was not like that of a magnet in being especially potent in particular spots; but, on the contrary, the wire throughout its whole length showed an equally intense attraction around its entire surface.

Expt. Connect a copper wire, about one line in thickness, with the poles of a platinum or carbon battery (§ 546.). On establishing contact, the wire will attract iron filings towards itself, so as to be completely enveloped with them: and it will retain them so long as the electricity is sent through it. Break the connection, and the filings will instantly fall.

A horizontal spiral, such as *fig.* 244., may be substituted for a rectilinear one. Cover it with a thin plate of glass or horn; strew fine iron filings uniformly on the plate, and on transmitting the current through the spiral, the filings will be seen to group themselves about the coils.

Fig. 244.



§ 567.

If an electric current pass near any small pieces of steel or iron which stand at right angles to the direction of its current, it will render them magnetic, and that end which is to the left of the current will be the north pole of the respective pieces.

Expt. Use a strip of copper as the conductor of a powerful battery, and at right angles to the direction of its current lay a fine sewing-needle, which may be insulated by means of a piece of Indian rubber, or paper, or by a silken thread, from the copper. Send the current through the latter, and the needle will acquire a magnetic polarity, and its north pole will lie to the left of the current, the observer being supposed to stand so that the current flows between him and the needle, *i. e.*, on that side to which the current would deflect the north pole of a magnetized needle (see § 546.).

Soft iron retains its magnetic property only so long as the current circulates and acts in it; hardened steel, on the contrary, retains for a length of time the magnetism imparted to it.

The current exerts a still more powerful influence by making it encircle the steel you desire to magnetize a considerable number of times. Even large needles may be rendered strongly magnetic, if they be insulated in a conductor coiled like a screw or a solenoid, through which a powerful current is transmitted. A momentary charge is sufficient permanently to impregnate the steel with magnetic virtue, that end which is next the north pole of the spiral becomes the north pole of the magnet (§ 554.); *i. e.*, the end, therefore, which lies on the left of the direction in which the current flows.

Helices are said to be *right-handed* when coiled forward in the direction in which the hand of a watch moves; *left-handed* when the coils run in the same way as the worm of a common screw. In the former the south pole of the needle will be found at the end where the current enters, and the north pole where it makes its exit; in spirals coiled to the left, the position of the poles is exactly reversed.

First Expt. Wind some copper wire about half a line thick around a glass tube one line in diameter and rather longer than the needle that is to be magnetized. If the wire is previously covered with silk, the glass may be dispensed with. Thrust the needle into this helix of wire so that it may be completely surrounded by it, and as soon as a sufficiently powerful current is transmitted through the wire, the needle becomes magnetic. By attending to the remarks already made, it will at once be known at which end the north pole will be.

Place a needle already possessing magnetic properties in a helix, such as we have just described, with its south pole where the north pole of an unmagnetized needle would be; send a current through the wire, and the poles of the magnet will instantly be reversed.

Since a momentary action of the current suffices to magnetize the needles, a similar result is obtained by sending a charge from a Leyden jar through the coil of wire; an experiment given already, § 497.

From these effects of the electric current we are enabled to understand the influence of lightning on steel rods and magnets referred to in § 545.

Second Expt. If the wire is coiled in one direction half the way along the glass tube, and then in the opposite the other half, a needle placed in such a helix will acquire three poles by the action of the current on it; viz., two similar ones, one at each end, and one dissimilar at the point where the direction of the current was changed.

§ 568.

In consequence of its low coercive force (§ 452.), pure soft iron becomes more strongly magnetic than steel, when encircled by a spiral electric current. The magnetic virtue thereby imparted is, however, only transient, as it vanishes on the current being discontinued. Iron bars, generally of a cylindrical form, about which an insulated copper wire runs in the form of a helix to conduct the current, are called *temporary* or *electro-magnets.* The most powerful specimens are obtained by bending the bar into the figure of a horse-shoe, the coils of wire being, however, continued as if the bar were rectilinear; its ends are then closed by a feeder of soft iron. They surpass all natural and all the other kinds of artificial steel magnets in suspensive power, several having been already constructed, and of no very great dimensions either, which are capable of bearing more than 2000 lb.

Both the bar and horse-shoe electro-magnets acquire at their extremities that polarity which the ends of the helix possess; that is to say, their north pole will always be to the left of the direction in which the current flows. If the current's direction be reversed, the poles of the magnet will be so too, and the transmission is generally of such short duration that the keeper either does not lose its hold of the magnet at all, or at most it recedes but little from it. If the current be altogether cut off, and the keeper be maintained in contact with the magnet, Watkins found that the electro-magnet retained for a length of time a considerable suspensive power (about half its full power); but that if the keeper were detached, the magnet entirely lost this power. Magnus further discovered, that electro-magnets acquire their extraordinary suspensive power only when their keepers are connected with them; it is the magnetism excited by induction in the keepers that imparts this power, for when the poles are not thus connected they are scarcely able singly to support the weight of the keeper.

Several philosophers have attempted both experimentally and theoretically to ascertain the laws on which this suspensive power principally depends, and by which it may be determined. Investigations of this kind were first undertaken by Fechner, Dal Negro, and Ritchie; they have subsequently been carried on more fully by Jacobi and Lenz, and most recently by Pfaff. The main results at which they have arrived are the following: —

1.) The amount of the suspensive force is immediately dependent *on the intensity of the electric current* which circulates about the iron; and it has hereby been ascertained, that the intensity of the magnetism excited in the soft iron *is exactly peoportional to that of the electric current.*

> By Ohm's fundamental law the intensity of the current may be estimated from the magnitude of the electro-motive force, and the degree of resistance to conduction that has to be overcome (§ 511.) in a short stout wire of good conducting power, such as copper. It depends, therefore, principally on the quantity of electricity passing through the helix; consequently, on the area of the electromotors, and on the absolute force with which it is excited; if the wires be long and fine, on the density of the current, and on the number of members in the battery.

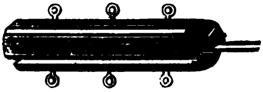
2.) If the intensity of the current continue the same, the magnet's suspensive force increases with the number of turns made by the wire; or, *the total effect of all the coils is equal to the sum of their effects if taken singly.*

3.) The attractive force of an electro-magnet increases as the mass of the iron composing it; and this increase *is proportional to the diameters of the iron cylinders, their lengths being equal.*

4.) The *structure of the iron* itself greatly modifies its influence; and, in fact, *the purer, softer, and more homogeneous the mass, the stronger the magnetism it is capable of receiving.*

5.) Lastly, it has been ascertained that, *the form of the mass of iron, or of the electro-magnet, influences its suspensive power.* Cylinders were found to carry greater weights than rectangular bars; and a hollow cylinder, from which a portion had been cut away, so that it formed (*fig.* 245.) a long horse-shoe magnet,

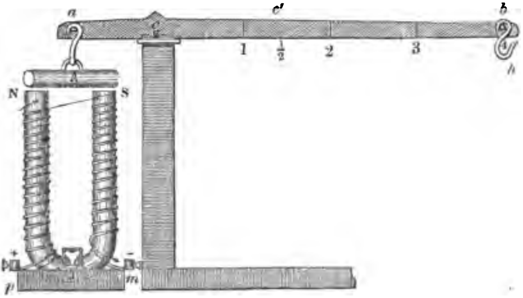
Fig. 245.



when viewed in the direction of its axis, but a very short one if taken as to its height, was capable of receiving a very great suspensive force; and lastly, a slight curvature of the polar surfaces added considerably to its power.

The following contrivance will be found convenient for estimating in a simple manner the suspensive force of an electro-magnet, either by weight or by human power of traction.

Fig. 246.



The horse-shoe NJS (*fig.* 246.), which stands vertically in a wooden foot, is fastened so that its arms point upwards. The manner in which the copper wire is coiled about it is seen from the figure. The ends carry two binding-screws *p* and *m*, which are either connected immediately with the poles of a battery of two elements, a carbon or platinum battery, or else it is connected with the latter by means of a commutator (*fig.* 203. § 546.). The different coils of the wire are insulated one from another by winding them so that they do not touch at any point; they are insulated with regard to the iron of the electro-magnet either by surrounding the latter with a silk band, or by coating it over with gum-lac varnish. The feeder A, which consists of a cylindrical piece of soft iron, is so fastened to the unequal armed lever *acb* that it moves at a short distance above the poles, whose faces are slightly hollowed out. The feeder having a free motion in this position, can be brought down so that its cylindrical surface just fits into the cavity of the poles beneath it. A stout hook *h* is attached to the other arm *b*; to it the scale pan is fastened, in which weights are laid to measure the magnet's power of suspension; or this force may be estimated by pressing or pulling the lever with the hand until the keeper is detached, in which case the true measure of the force is obtained by supporting the lever in the middle *c'*. It is scarcely necessary to add that in such experiments as we have been describing, the foot of the apparatus must be secured by a clamp, so as to render it immoveable.

This curious and powerful kind of magnet was discovered by Sturgeon in 1825. Subsequently Henry and Ten Eyk, in America, constructed some on a large scale. One horseshoe magnet made by them, and weighing 60lbs., would support more than 2000 lbs. More recently electro-magnets have been made of the ordinary form by Joule and Radfort. *Fig.* 245. represents one of Joule's, which weighed 15 or 16 lbs., and carried a weight of more than 2500 lbs.

§ 569.

If a rectilinear electro-magnet be made to turn in a horizontal plane about its centre, it will act in the same manner as a declination needle, or a solenoid; that is to say, it will assume a polar position. If on its attaining this situation the current in its wire be reversed, the poles of the magnet will instantly be reversed, and the consequence will be that it will begin to revolve in order once more to regain its polar position, on attaining which its magnetism becomes again changed, and hence a perpetual rotation of the magnet about its middle. This rotatory movement, which in the case supposed was owing entirely to the influence of the earth's magnetism, may be rendered more violent by causing the unvarying poles of a common magnet, or of an electro-magnet, to act upon those points of the revolving one where the change in the current takes place. According to the laws of magnetic polarity there arises first an attraction between dissimilar poles; as soon as these, by the change in the current, become similar there ensues a powerful repulsion. This alternate action is maintained so long as the continuance of the electric current keeps up the temporary magnetism. Ritchie, who in 1833 invented these rotating magnets, first entertained the idea of applying this rotation as a motive power to machinery.

Fig. 247. and *fig.* 247 *a.* give a vertical and a bird's-eye view respectively of an apparatus of this kind, which, besides generating a rotatory movement, may be used as a contact-breaker. S N is a common horse-shoe magnet, with its poles uppermost: *nsc* is the small electro-magnet, which turns about the vertical axis *cd*, whose point rests in a depression

Fig. 247.

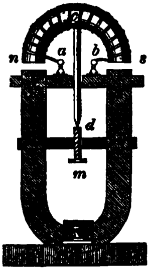


Fig. 247 *a.*

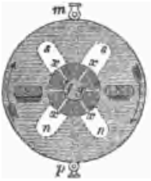
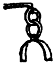


Fig. 247 *b.*



in the screw *m*: the poles *n* and *s* of the lesser magnet are at a small distance from those of the great horse-shoe, whose poles S and N pass through a wooden circular plate; between these poles the two halves of a copper ring are let in, so as to be insulated at *f* and *g* by two partitions of wood or ivory, which part them asunder. From these points conductors are carried through the wooden disc, ending at its circumference in binding screws at *p* and *m*, by which the half rings of copper are connected with the poles of a constant battery. These two copper plates, acting now as the poles of the battery, are put in contact with the ends *a* and *b* of the helix of wire, and thus the current circulates about the electro-magnet. To insure a complete metallic contact between the points where the current passes off to the wires, and at the same time to reduce the friction to the utmost, it is best to attach to the ends *a* and *b* some extremely fine platinum wire, twisted so as to form a fork (*fig.* 247 *b.*), and trace over the copper plate, which may be either amalgamated, silvered, or gilt. At the instant when these fine wires cross the bridges *f* and *g*, and touch the other copper plate, the poles of the electro-magnet are reversed, as is understood readily from the remarks already made. The partition *x* which projects above the copper plate, and which, like those at *f* and *g*, may be of either wood or ivory, would insure that the current should be interrupted every half revolution.

§ 570.

Many philosophers and mechanicians, in both the old and new world, were induced, from a consideration of Ritchie's rotating electro-magnet, to investigate, both practically and theoretically, how far electro-magnetism would be available, if applied as a motive power to machinery.

The principle on which all machines act that are *set in motion by electro-magnetism*, is mainly the great attractive force exerted by the dissimilar poles of an electro-magnet, and the subsequent change of this attraction into an equally strong repulsion, when, by the change of the current in the spiral, similar poles are made to act on each other. — We are indebted to Professor Jacobi, of Petersburg, for the most complete and varied investigations, both of a practical and theoretical nature.

> A machine was constructed, according to the laws developed by Jacobi and Lenz, in 1831, its useful effect amounted to between ¾ and 1 horse power (§ 421.).
>
> In consequence of what has already been effected, these machines possess a great practical interest, and since experience has ever shown that discoveries of this nature are not brought for years to the highest degree of perfection of which they are susceptible, every unprejudiced person will look with satisfaction at what has already been accomplished, and as the existence of this force is fully established, the hope may reasonably be cherished that further investigation will enable us to apply it more extensively. Whether this new motive power will ever replace steam, as many have confidently asserted, we are not yet in a condition to say positively: before that can happen we must be enabled to generate electro-magnetic force of any degree of strength that we please, as we can steam; it must possess the power of imparting to machinery every required velocity; it must be capable of being regulated as steam power is, at the pleasure of man; and could even all these requisites be complied with, and though it possessed the advantage of involving no risk of life in its controul, there would remain one important element to be considered, viz., whether its economical effect, *i. e.* its useful effect, when compared with the cost of generating and working it, exceeds that of steam. The main point would therefore be, that we should find materials for generating this force as abundantly supplied as those by which steam is created: for with the present construction of electro-magnetic machines, and with the materials now used for producing the force, it is out of the question to think that it can be substituted for a fraction of the many millions

of horse power represented by existing steam engines (§ 420.). Whilst penning these lines, the recollection involuntarily forces itself upon my mind of the illusory anticipations, formed but a few years ago, that steam power was to supersede gunpowder (§ 420.).

II. MAGNETO-ELECTRICITY,

OR THE INDUCTIVE INFLUENCE OF ELECTRIC CURRENTS.

A. *Electric Currents excited by means of others.*

§ 571.

After the electro-magnetic discoveries had established the fact that electricity, in a state of motion, possessed magnetic properties and exerted a magnetizing influence, the natural conclusion was speedily drawn that, conversely, magnetism would call forth electrical phenomena.

Now, as according to Ampère's theory of the nature of magnetism (§ 497.), magnets are assumed to be bodies about which electric currents circulate, the next thing to prove was, what influence such currents would exert on other bodies in a state of electrical equilibrium. The investigations on these points led to the following results:—

1.) *Electric currents act precisely as electricity in a state of tension would act on conductors within the sphere of their influence, that is, they by induction excite currents again in these bodies.* The electric currents thus generated are called *induced* or *secondary* currents, whilst those which existed originally are termed the *inducing* or *primary* currents.

2.) *A secondary current will be elicited in a closed metallic conductor, when brought near to or when removed from a current already existing, also when an electric current is called into existence or is suspended in its neighbourhood.*

3.) *These secondary currents are only of momentary duration, whereas the primary are permanent.*

4.) *The secondary current which is first generated, viz. that which is formed by bringing the unelectrified conductor near to the* *primary current has the* opposite *direction to it, whereas the second or final one, which is formed by the removal or suspension of the primary current, has the* same *direction with it.* Hence it follows that the secondary currents always have the contrary direction to that which a current in the unelectrified conductor must have had to cause their approach or recession.

Further research showed that a secondary current that had been elicited by a simple or rectilinear primary one, and that had but a small intensity, became much more powerful when the conductor of the primitive and that of the secondary currents were coiled under each other in a spiral form, because by this means the single force was multiplied in the same manner as in a galvanometer, §§ 512. and 547.

The brief duration and the small intensity of currents excited by induction, caused them to be so long overlooked by many distinguished men of science. Faraday was the first who, towards the close of the year 1831, discovered the laws by which the inductive influence of electric currents is governed; their existence he proved by increasing their effect through using a great many coils of wire.

This distinguished philosopher endeavoured to account for the brief duration of these currents agreeably to the laws of the induction of electricity in a state of tension, thus (§§ 478. and 483.). At the moment when electrical equilibrium is disturbed by a primary current in a closed conductor, it will attract one electricity and repel the other. Thence two currents arise, one running in the opposite direction to the primary current, the other in the same direction with it. Now the latter, by the laws of electric currents (§ 549.), will be attracted by the primary current, its action will be thereby suspended whilst the other will move on with great velocity. The induced conductor, during the continuance of the current which acts on it, is in a peculiar latent state, called by Faraday the *electrotonic* state, resembling a conductor put in a state of tension by induction. When this condition terminates, the current that had been held back so long as it lasted is set at liberty and moves in the direction of the exciting current.

The following experiments will display the creation of these secondary currents, their brief duration, and the laws regulating their direction.

First Expt. Two fine copper wires covered with silk will serve as conductors of the primitive and secondary currents. Coil both under and over each other about a wooden cylinder in which there is a deep groove, so that the entire number of turns may amount to several hundred. *Fig.* 248. represents one of these induction spirals; *a* and *b*

Fig. 248.

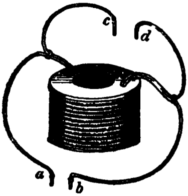
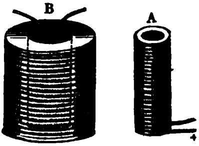


Fig. 249.



are the ends of one, *c* and *d* those of the other wire; and that the ends of the respective wires may be readily distinguished, it is advisable to cover them with silk of different colours. Connect the ends of one wire, *ex. gr. a* and *b* with the poles of a powerful constant battery, then the current in this conductor will circulate close to the other conductor without being able to pass over into it. The second wire will accordingly serve as the conductor of the secondary current, and that the effects of induction in it may be readily seen, connect its ends *c* and *d* with a galvanometer. At the moment when the battery is connected by means of the first wire, the deflection of the galvanometer needle shows a secondary current to have been elicited in the under wire. If the primitive current in the first wire go from *a* to *b*, the needle would show that the secondary current had gone from *d* to *c*. After a few oscillations the needle reverts to its original position, thus proving that the induced current had ceased to exist. Interrupt the primitive current by breaking the connection of the battery, and the needle will instantly turn in the contrary direction; showing the existence of a current in the under wire flowing from *c* to *d*, in the direction therefore of the principal current whose action had been suspended.

Second Expt. To show how secondary currents are produced by bringing one conductor near to another and by withdrawing it, the latter being traversed by electricity, it will be necessary to use two separate induction spirals. The inducing spiral whose ends are connected with the constant battery, consists of a wooden roller on which are several hundred coils of copper wire about one line thick, as shown in *fig.* 249. A; the wire is covered with silk. The other in which the secondary current is to be generated consists of a similar wooden roller, *fig.* 249. B, hollow in the middle and large enough to slip over the other. It contains some 1000 or more coils of fine copper wire coated over with silk; its ends are connected with a galvanometer. The phenomena described in the preceding experiment occur when the second spiral is thrust over the other, and when it is detached from it.

§ 572.

Soon after the discovery of these secondary currents it was found, as was to be anticipated, that they produced not merely magnetic, but also physiological and luminous phenomena, like other electrical currents; on account of their alternate action they exert no chemical influence. To render their physiological effect on the human frame perceptible, there must be a rapid succession of breaks in the primary current; this may be effected by inserting a contact breaker in the circuit.

When a frog's leg was connected with the ends of the induced spiral, contractions took place on each opening and closing of the battery. Sparks also accompanied each of these changes when the amalgamated ends of the wires were brought together.

To magnetize a steel needle, place it in a spiral wire just as when a permanent hydro-electric current is used, the ends of this spiral being connected with those of the induced spiral. Only one of the secondary currents should be allowed to pass through this conductor, or else the magnetic influence exerted by the one current will be annihilated, or at least impaired by the other which flows in a contrary direction.

A shock may be received from a current proceeding from one element of a constant battery, if the metallic ends of the spiral in which the secondary current is generated are grasped with wet hands, and the effect will be heightened if the ends of the wires are furnished with such conductors as we have described in expt. 6. § 515., and the person who is to receive the shock holds these instead of the mere wires. With the common voltaic current a pile of at least thirty pairs of plates is required to produce a shock; the current of the single battery is in this case rendered more powerful by being transmitted through repeated coils of the wire.

§ 573.

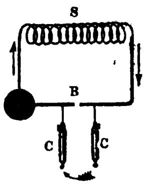
Every electric current, on the connexion with the battery being broken and renewed, excites a special current in its own conductor. Faraday attributes this to an inductive influence which the coils of the same spiral exert on each other: the current thus produced he calls the *extra-current*. The extra-current generated on connecting the battery, like the secondary current, has the contrary direction to the primary, the predominance of the latter therefore neutralizes it; that which ensues on breaking the connexion has the same direction as the primary current, and is remarkable for the effects it produces, being distinguished especially by the intensely bright sparks and the powerful shocks it gives off.

First Expt. Connect the mercury cups at the poles of a simple but strong voltaic battery (best of all of platinum or carbon), by means of a short copper wire; on breaking and renewing the connexion a very feeble spark will be obtained, but if the poles are connected by the long wire of an induction spiral each time the ends are inserted in the mercury cups and are removed from them, a vivid spark and an audible report will be observable.

Second Expt. Connect the poles of the battery with the metallic conductors which are to be grasped in the hands, and the nerves will be affected each time the connexion is established and broken; but the intensity of the shock will be increased within certain limits in proportion to the number of turns in the helix of an induction spiral inserted between one pole and one conductor.

Both the luminous phenomena and the electric shocks are rendered more forcible by interposing any contact-breaker; the sparks are remarkably brilliant if a Ritchie's rotatory electro-magnet (*fig*. 247.) is employed. To obtain the rapid succession of shocks the contact-breaker must be inserted in that part of the conductor which is between the conductors that are held in the hands. *Fig*. 250. will render this arrangement more intelligible; E is the battery, S the spiral connected with one of its poles, B is the contact-breaker, and C C are the conductors. At each interruption the extra-current runs from the conductor through the human body.

Fig. 250.



When the current is interrupted and renewed with sufficient rapidity and continuance, the extra-current, as Faraday has proved, exerts thermal, chemical, and magnetic influences.

§ 574.

Even the momentary current of frictional electricity, obtained by discharging a Leyden jar or an electrical battery, excites, in closed conductors standing near the conductor of the momentary current, induced or secondary currents, whose properties have been investigated by P. Riess and Dove in a comprehensive series of ingenious experiments. An instantaneous primary current of this kind generates only one secondary current, which has always the same direction with itself, and which produces effects thermal, magnetic, and physiological, strictly analogous to those caused by permanent electric (voltaic) currents. Want of space forbids our entering more into detail as to the properties of these currents.

B. *Electric Currents generated by Magnets.*

§ 575.

It was to be expected from the discoveries made as to the inductive influence of electric currents, that if Ampère's hypothesis were correct, magnets would produce effects strictly analogous to those displayed by an induction spiral, through which there flowed a stream of voltaic electricity. The experiments performed to establish this point have fully proved it. *A magnet by induction excites in an unelectrified closed conductor a current both on being brought near to, and on being removed from the latter. While the magnet is at rest, and near to the conductor, no current is perceptible in the latter.* These secondary currents have the same directions as they would have received from a magnet (§ 557.), according to the fundamental law of the induction of electric currents (§ 571.), based on Ampère's hypothesis.

Our first knowledge of the existence of these *magneto-electric currents*, as they have been called, is due to Faraday, who discovered them towards the close of 1831, simultaneously with the secondary currents that are generated by voltaic currents.

The following may be regarded as the fundamental experiment:—

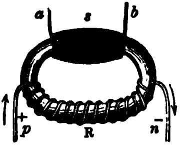
Expt. Insert one leg of a powerful horse-shoe magnet in the hollow cylinder of an induction spiral, *fig.* 249 B, whose ends are connected with a galvanometer, and the deflexion of the needle will show that a secondary current has been generated in the spiral whose direction is contrary to that of the currents circulating about the magnet. — If the leg of the magnet remain at rest in the cylinder, the galvanometer needle will, after a few oscillations, resume its normal position; the copper spiral is consequently in an *electrotonic* state (§ 571.). — Withdraw the magnet after the needle has become steady, and it will again deviate, but in a contrary direction to that in which it moved when the magnet was inserted in the spiral. — Insert the other pole of the magnet in the cylinder and the direction of the needle's deflexions will be reversed. — In these experiments the wires from the helix must be long enough to prevent the magnet's acting on the galvanometer needle.

§ 576.

Soft iron, which has been rendered temporarily magnetic by the permanent electric current of a voltaic or of a thermo battery, or by induction from a steel magnet, excites secondary currents in an induction spiral in precisely the same manner as a magnet would. The first case may be verified by surrounding an electro-magnet in an induction spiral, then establish and break the connexion of the battery from which the current proceeds to its helix, and it will be alternately in a magnetic and in an unmagnetic state. In the other case the same effect follows if a piece of soft iron, placed in the induction spiral, be alternately magnetized and demagnetized by approaching and withdrawing a powerful steel magnet.

First Expt. The Magneto-electric Ring, fig. 251., is one of the most simple pieces of apparatus for generating magneto-electric currents by means of an electro-magnet. It consists of a bar of iron about 1 inch thick, bent round, so as to form an oval ring, whose longer inner diameter may be somewhat about 3 or 4 inches. One half R is converted into an electro-magnet, by having some insulated copper wire of sufficient thickness twisted round it, the ends of the wire being connected with the poles of a constant battery; the other half, which answers to the feeder of an electro-magnet, is surrounded with the inductive spiral *s*. Connect its extremities *a* and *b* with a galvanometer, and its needle will

Fig. 251.



show, on the connexion of the battery being broken and renewed, the same effects as if its place had been occupied by an electro-magnet.—A common electro-magnet might have been used in performing this experiment, if its feeder, by which the poles were connected, were inserted in an induction spiral.

Second Expt. To show that these currents may be generated by the inductive influence of a steel magnet, bring a feeder, such as we have just described, near to the poles of a powerful horse-shoe magnet, and then withdraw it. On bringing the pole of the magnet near the two ends of the feeder, the galvanometer needle, which is connected with its spiral, will show the existence of a current, whose direction is opposite to that of the current which, by Ampère's theory, is supposed to encircle the soft iron that has been converted into a magnet. On withdrawing the magnet, the contrary deviation of the needle proves that the second secondary current has been generated, and that its direction is the same as that of the current which had just been suspended in the iron.

§ 577.

Lenz has investigated and discovered the laws which regulate the magneto-electric force excited by magnetism in the induction spirals. The results obtained by this philosopher coincide exactly with the laws which he and Jacobi had previously found to regulate the intensity of the electro-dynamic force excited by voltaic currents (compare § 568.). These laws are,

1.) That the magneto-electric energy excited in an induction spiral by means of magnetism, is equal to the sum of the electromotive forces of all the individual coils of the wire (Ohm's fundamental law, § 511.).

2.) "Cæteris paribus," that is to say, with equally powerful currents, the magneto-electric force will be nearly proportional to the number of coils, the thickness of the wire exerting no influence on it: its intensity will, however, be slightly diminished by increasing the width of the coils.

§ 578.

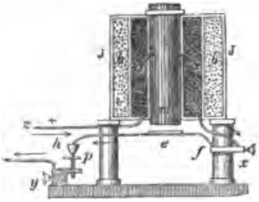
The action of a hydro-electric induction spiral may be thus combined with that of an electro-magnetic spiral: place a piece of soft iron within the hollow cylinder of a spiral through which the primary current flows, and the secondary current generated by the combined influence of the two forces will be more powerful than if excited by either of them singly. The soft iron becomes magnetic every time that the contact of the voltaic battery is established; it loses its magnetic properties again when contact is broken; it acts therefore in both cases inductively, like the voltaic current on the outer coils of wire. In this kind of induction apparatus the extra current which is generated at the moment when contact is broken, possesses remarkable energy in giving off sparks and shocks; subsequent observation has shown that these effects are rendered still more powerful if a bundle of iron wires be used instead of a solid cylinder (*a*).

On these principles have been constructed *galvano-magnetic induction machines*, which have been variously applied, but whose principal use is for medical purposes; they consist of an induction spiral connected with a hydro-electric battery, which is fitted up with an apparatus for establishing and breaking contact with great rapidity.

a.) Bachhoffner and Sturgeon appear to have first noticed that a bundle of wires, insulated by a coating of varnish, gave a more powerful extra current than a massive bar of iron. Magnus and Dove tried to ascertain the cause of this increased effect; they found that when the wires were inclosed in a metal case, the force of the current was the same as if it had been sent through a solid iron. But when the tube was slit, or when the wires were not inclosed at all, the efficiency of the current was greatly heightened. Dove found, on prosecuting his inquiries still farther, that two perfectly equal induction spirals, provided with different bars or sets of wires, even if they deflected the needle of a galvanometer equally, gave shocks of unequal intensities; he therefore inferred that the increased physiological effects depend partly on the internal structure of the iron, partly on the discontinuity of its mass, and that the greater effect is owing to the more rapid suspension of the current caused by this discontinuity; the greater intensity of the shock, caused by rapidly establishing and breaking the contact of the battery, admits of a similar explanation.

b.) One of the simplest and most ingenious contact-breakers for machines of this kind, has been invented by M. Wagner, of Frankfort-on-the-Maine: it possesses the advantage of simplicity of construction, and also that of having its motion maintained by the electro-magnetism elicited, in this respect resembling Ritchie's rotating electro-magnet. *Fig.* 252. will show its construction; the mechanical combination will, however, admit of various modifications.

Fig. 252.



I I is a sectional view of a double induction spiral, *r r* is the wooden roller on which the inner spiral of stout copper wire *a* is wound, this serves as a conductor of the primary current, and over this the finer wire *b* is wound as a conductor of the secondary current; *m* is the bundle of iron wires in the axis of the spiral, projecting with its lower pole a little beyond the opening in the wooden cylinder. The end *z* of the wire forming the inner spiral is connected with one pole, and the other, *x* and *y*, is connected with the other pole of a constant battery. The portion of the conductor *f e h p* between the two binding-screws *x* and *y*, acts as the contact breaker. It consists of a copper wire, flattened at *f* into a feather-edge, which may be soldered or screwed on to the binding-screw, *x*. A leaf of iron, *e*, is fastened on this wire under the electro-magnet; at *h* it is bent downwards, where it expands into the hammer *h*, terminating in a platinum point by which the conductor rests upon the copper plate *p*, which serves as the anvil. When the hammer rests on the anvil, the contact of the battery is established, and the bundle of wires *m*, magnetized thereby, attracts to itself the plate *e*, and thus raises the hammer *h* from its point of support *p*. Contact is now broken, the wires part with their magnetic properties, the hammer again descends on the anvil, and once more establishes contact. This process is repeated so long as the connexion is maintained with the voltaic apparatus.

The sparks of the extra current are emitted between the hammer and the anvil, and are most vivid when the surface of the latter has been recently amalgamated. A shock may be received from this current by connecting the metal conductors at *x* and *y* with its conductor. To observe the thermal, chemical, and magnetic effects, the bodies to be subjected to the action of each should be interposed between the binding-screws *x* and *y*, so that when the principal current is interrupted the circuit of the battery may be completed by them.

To use the physiological influence of the secondary current, the conductors are to be connected with the ends of the wires of the outer induction helix.

The shocks emanating from long induction wires and a large bundle of wires, especially if the primitive current proceed from a platinum or carbon battery, are almost too strong to be borne, and may be transmitted through a circle of 50 or more persons, if they lay hold of each other with moist hands.

§ 579.

After the discovery of the magneto-electric induction currents, several philosophers applied themselves to discover how they might be rendered continuous, and how to convert their alternating direction into a constant one. An apparatus fulfilling these requirements is termed a *magneto-electric rotatory machine*. Such a machine may be used as a substitute in part for a common electrical machine, and in part also for a voltaic pile, as it is capable of producing electric sparks, incandescence and fusion of wire, intense light at charcoal points, physiological effects, chemical decompositions, and magnetic action of many kinds. The first machine of the kind was constructed in 1832 by Pixii, soon after it was improved by Clarke and Saxton, and recently it has been perfected by Von Ettinghausen and Dove.

One of these machines consists of three principal parts, viz., a powerful horse-shoe magnet, capable of supporting from 50 to 100 lbs.; a keeper of soft iron of similar shape; and two induction helices, each of which goes round one leg of the keeper. The large magnet is that part of the machine from which the inductive influence emanates uninterruptedly, and which occupies the place of a permanent electric current. The feeder forms a whole with the induction helix connected with it, and is that part of the apparatus on which the magnet exerts its inductive influence, rendering the legs of the feeder magnetic, and thus exciting the secondary currents in the helices. This feeder, or *inductor*, as it is called, is fastened to a metallic axis, passing between its legs: by means of a wheel acting on this axis, the inductor is made to revolve rapidly, with its ends near the poles of the magnet. The extremities of the inductor, *s n*, *fig.* 253., and the poles N S of the magnet, are alternately brought into two opposite positions over against each other, and are then quickly withdrawn; so that the end *s*, for instance, which stood opposite to N, will, after half a revolution, resume its original position. During such a half revolution of the inductor (by which its ends will be brought into the reverse position before the poles of the magnet so that *s* will come opposite to S and *n* to N) there will be an uninterrupted current in one direction through the helix. Its intensity will, however, vary, decreasing till it reaches a minimum, and then increasing to a maximum, When the ends of the inductor have reached their new position with regard to the poles, the direction of the current in the helices alternates; and, on continuing to turn till the next opposition of the ends of the feeder to the poles of the magnet, there will be a similar variation in the intensity of the new current; so that, with a continued rotation of the inductor, there will ensue a corresponding variation in the directions and intensities of the currents generated. But that the currents induced in the helices, whether with or without a break, may be carried in one single direction by means of a conductor, the two free ends of the wires must be so connected with one part of the revolving axis of the inductor that it may in a measure embrace both the poles from which the current proceeds. To effect this, that part of the machine is so contrived that it performs the office of a commutator or gyrotrope (§ 546.), by means of which, after every half turn, the direction of the current in the induction helices is reversed, and as this reversal is opposite to that which obtains in the feeder of the inductor, the current is maintained in one constant direction. To break the current, which is necessary for many purposes, some contrivance must be made with the commutator by which the continuity of the conductor may be broken for an instant every half turn of the inductor exactly when the current is at its maximum intensity. There are various ways of attaining one or other of these ends; and in the mode by which they are accomplished consist the chief points of distinction in the various machines of different philosophers.

In order conveniently to obtain the various effects enumerated above with such a magneto-electric current, the resistance to conduction must be estimated which the current will have to overcome in the bodies on which it is to act. If this resistance be but small the induction helix will require but few coils; but a thicker wire must be used. The ends of the wires of the two helices are to be so joined together that the current in them may move on in one direction, by which means the whole wire will act as if it had half the length and twice the strength. This *quantity inductor*, as Von Ettinghausen calls it, acts in a manner analogous to a simple hydro-electric battery having a large excited surface. It serves principally for generating sparks at the break-piece, for the phenomena of incandescence, and for the magnetic operations; for these last, however, the current ought not to be broken, nor ought its direction to be changed. On the contrary, if the current have a considerable resistance to overcome, as happens when it is to be conducted through the human frame, or when employed to effect chemical decompositions, its intensity must be increased; which is effected by using a helix of finer wire wound several thousand times, so that it forms one continuous whole round both the legs of the feeder, like the helix round an electro-magnet. The same effects may be produced by means of such an *intensity inductor* as with a voltaic pile consisting of a large number of pairs of plates. It is therefore used chiefly for generating powerful physiological effects by alternately breaking the current, for raising charcoal points to a state of incandescence, and for chemical action; the current, however, must in these cases remain unbroken, and with its direction unaltered.

Fig. 253 *a.* gives a bird's-eye and *fig.* 253 *b.* a perspective view of a magneto-electric machine. N J S is a powerful compound magnet, fastened in a horizontal position. *s* and *n* are the induction helices of the feeder, whose axis *a b* is connected with the large wheel W by an endless strap, which runs over the small grooved wheel *r*: this sets it in motion, so that its polar surfaces turn round close to the poles of the magnet. The part *c b* of the axis acts as a commutator: it consists of two parts, one of which *m* has a metallic connexion with the feeder, while the other *p* is insulated by a cap of horn or wood slipped over it. The free end of one induction helix is connected with the feeder at *c*; that of the other, on the opposite side, with the insulated metallic cap *p*; so that in this way the two metallic capsules *p* and *m* secure the ends of the helices from which the current flows. The conduction of the current from these parts is effected by two steel springs, one of which *f* lies above and the other *g* under each of the metallic caps, and which, being screwed on brass or copper stems, are connected with two binding screws P and M, which thus, in a manner, constitute the two poles of the entire machine. If now we assume that in the position of the helices represented in *fig.* 253 *a.* P is the positive and M the negative pole, after one half turn of the inductor P would become the negative and M the positive pole, the direction of the current would consequently be reversed. But so soon as this change took place in the two induction spirals, the electrical condition of the polar surfaces *p* and *m* of the commutator would be reversed too; and as at the same time when this happened the two springs *f* and *g*, by which the current is conducted to P and M, are brought into contact with these oppositely electrified parts *p m*, the current becomes again changed; whence it is readily seen, that if P and M are connected the current goes unchanged as to its direction from P to N. To give shocks and to emit electric sparks a rapid succession of breaks is indispensable. The break must occur on the current's attaining its maximum intensity, which happens when the induction helices are midway between the two poles of the magnet, or vertically one above the other, as in *fig.* 253 *b.* To effect this there are depressions or holes *o*, *fig.* 253 *a.* in the middle of the two halves *p* and *m* of the

Fig. 253 *a.*

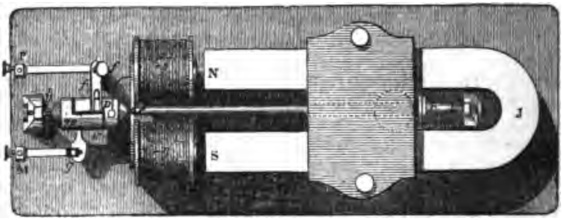
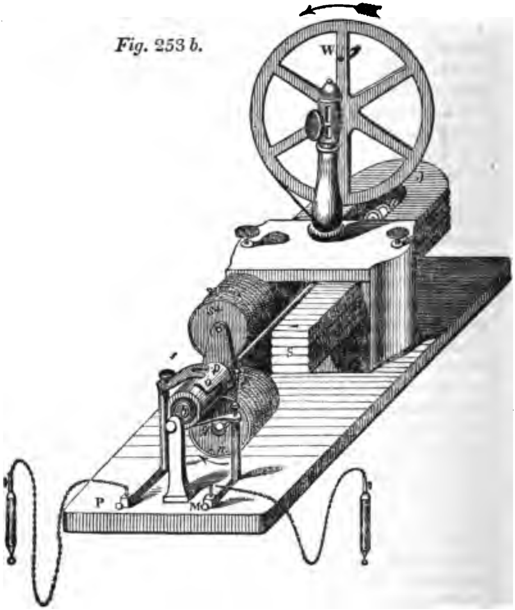


Fig. 253 *b.*



commutator; *i.e.* about 90° from the places where the change occurs in the current. The forked spring *f* is then so placed that one half lies on the part *p* of the capsule when it moves on without any break, whilst the other is bent so that it falls into the depression *o* as the inductor turns round, and thus breaks the conduction and the current; in like manner, the second spring *g* is bent so as to come on the unbroken part of the commutator *m*. This position of the springs is shown in *fig.* 253 *c.*

Fig. 253 *c.*

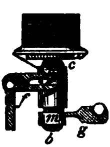


Fig. 253 *d.*

To obtain the physiological effects, and especially the magneto-electric shocks, in rapid succession, connect the metallic conductors (§ 515.) with the binding screws P and M; grasp one in each hand, and set the machine in action. Two shocks will be felt at each revolution, and if the inductor be whirled round rapidly the muscular contraction will become too violent to be borne. The same arrangement of the springs will serve to show luminous phenomena as generated by magnetic induction. They will be visible at the breaks in the conductor at the instant when the spring *f* falls into one of the holes *o*. A vivid white electric light will appear in the groove, and if a steel spring be presented to it, it will immediately be surrounded with reddish sparks. As we have already remarked, these phenomena will be most brilliant if a quantity inductor is used, in which case the sparks will frequently have a length of several inches. The chemical effects, for producing which the intensity inductor will be the best adapted, may be obtained by using a constant direction of the current (which may be ensured by placing the springs *f* and *g* in the position *fig.* 253 *a.*), and connecting the electrodes of a decomposing apparatus with the two binding screws P and M. The decomposition of water, as also of an alkaline or heavy metallic salt, may be effected in the same manner as by a hydro-electric current. Woolrich in England and Stöhrer of Leipzig have successfully applied these currents to electro-gilding and silvering (vide § 519.). The splendid light of the charcoal points is obtained by using two of these points to establish contact (§ 514.), having previously connected them with the poles of the machine. To render platinum wire incandescent the quantity inductor should be used as shown in *fig.* 253 *a.*: secure a short, thin piece of platinum wire between two copper wires covered with silk and twisted into a fork, their other ends being fastened in the binding-screws P M. In like manner thin iron and steel wire may be burnt; or twist the wire you intend to burn about a wire of pure metallic copper connected with one pole of the machine, and touch the other pole with the short free end of the iron wire. Lastly, to produce its magnetic effects, such as the deflection of the needle, the excitation of temporary magnetism in metals and electro-magnets, and the various electro-magnetic rotations, convey the constant current of the quantity inductor from the two poles of the machine through the electro-magnetic apparatus used in the particular experiment.

An electro-magnet may be substituted for a steel one in these machines, and then the rotation of the inductor will be effected by the changes of the current in the electro-magnet. This variation was first introduced by Pohl.

§ 580.

The discoverer of magneto-electricity could not fail, from working out the laws of magneto-electric induction, to hazard a conjecture that the earth itself must necessarily act in this respect also like an electro-magnet. At first he succeeded only indirectly in obtaining such an effect from terrestrial magnetism by thrusting an induction helix over a bar of soft iron, the ends of the helix being connected with a delicate galvanometer, and then placing the bar in the same position as the dipping-needle. By the inductive influence of terrestrial magnetism the iron bar acquired a north pole at its lower extremity (vide §§ 446. and 457.), and thereby induced a current in the helix, which, as the deflection of the galvanometer showed, was the same as we should have had by inserting the north pole of a bar magnet within the helix (§ 575.). The same effect followed when the helix was put in the position of the dipping-needle, and the cylinder of soft iron was thrust into it. On withdrawing the cylinder the needle was deflected in the contrary direction, precisely as if the north pole of a bar magnet had been withdrawn from the helix. Faraday subsequently succeeded in producing induced circulating currents, in various ways, by the influence of terrestrial magnetism. Copper wire, for instance, was coiled round a rectangular wooden frame, each of whose sides was about two feet long, and the ends of the wire were connected with a delicate galvanometer; the frame was then set in rapid motion, with its plane in the magnetic meridian. It was turned from W. to E., and the deflexion of the needle showed that an electric current was produced answering to the terrestrial current, which, from Ampère's hypothesis, is supposed to flow from E. to W. On withdrawing the conductor from this position, or on reversing the movement, the needle was deflected in the contrary direction. These effects which are extremely feeble of themselves, may, by a number of movements answering to the vibrations of the needle, be so increased in force as to deflect it 180° from its normal position.

§ 581.

On the electric currents excited by magnetic induction depend all the phenomena which conducting bodies display when magnets are moved over them, or inversely when the conducting bodies themselves are in motion and their movements are affected by the action of magnets. These phenomena may be divided into two classes, viz. such as attend the vibrations of magnetic needles in a state of proximity to non-magnetizable bodies, and such as arise between a magnet and one of these bodies, when one or other is made to rotate near to the other. The general name of *Rotatory Magnetism* has been given to all this class of phenomena.

§ 582.

Among these phenomena must be reckoned the diminution sustained by the oscillations of a magnet performed above a plate of metal. The isochronism of the oscillations continues unimpaired, but the arcs moved through by a declination and by a dipping-needle, as also those of a magnet swinging as a pendulum, are less if performed in the proximity of a mass of metal than they would otherwise be. The influence exerted by the metals varies in degree, that of copper and silver being greatest, and that of mercury the least; in all cases the effect is increased as the metal is brought near to the oscillating magnet.

The phenomena (see § 463.) observed by Coulomb in 1802, and by Hansteen, were owing to these influences. Arago investigated the subject more closely in 1824, in order to discover what influence the different metals exercised on magnetic needles vibrating near them. Seebeck pushed his researches still further, and arrived at the following important results. He first found the relative retarding force of the different metals on a magnet. A declination needle which performed 216 oscillations in the common air in reducing its arc from 45° to 10°, had its excursions reduced equally when the following metals were presented to it at a distance of 3 lines, viz.

Over Mercury after 112 oscillations,
— Bismuth — 106 —
— Platinum — 94 —

Over	Antimony	after	90	oscillations.
—	Lead	—	89	—
—	Gold	—	89	—
—	Zinc	—	71	—
—	Tin	—	68	—
—	Brass	—	62	—
—	Copper	—	62	—
—	Silver	—	55	—
—	Iron	—	6	—

He found further that the retarding effect increased as the number of plates, or the thickness of the single plate, if one only were used, was increased; this must be considered as holding good only within certain limits, no corresponding influence attended an increase of the surface; the effect of all the metals diminished exactly as the distance increased; the number of oscillations underwent no change if glass, wood, or paper, were interposed between the metal and the needle; heating the metal plate produced no modification in its influence; any disturbance in the connexion of the different parts of the plates diminished their influence on the magnet, and lastly, heavy needles were more easily affected than light ones.

Arago found in 1826 that even non-metallic substances, as water, ice, glass, &c., exerted a disturbing influence on the oscillations of needles, but in a much lower degree than the metals.

§ 583.

Immediately connected with the phenomena we have just explained, are those which arise when a magnet at rest is suspended over a metal plate in a state of rapid motion, or when a horse-shoe magnet revolves with its poles uppermost beneath a plate suspended horizontally above it. These are properly the *phenomena of magnetic rotation;* they were first noticed by Arago in 1826, and have since been repeatedly observed by other philosophers.

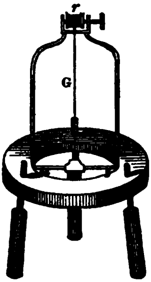
They are as follow:

A declination needle suspended a little above a plate of metal is deflected from its polar position on a rapid rotation being imparted to the latter about its centre; its deflexion will be in the same direction as that in which the plate turns; it increases as the rotation becomes more rapid, and on its amounting to 90° the needle revolves with the plate.

Babbage and Herschel performed the converse of this experiment of Arago's, by making the magnet to revolve under a metal plate suspended freely above it, and found the movement of the plate in this case to correspond with that of the needle in the former.

First Expt. These experiments will be most easily performed by using the whirling table (*fig.* 7. vol. i.), on the revolving axis of which fasten a copper plate two or three lines in thickness, and cause it to revolve with sufficient rapidity. Over the copper plate or disc place a table, *fig.* 254., in which a circular hole is cut of the same size as the disc; close the opening with a pane of glass, and bring the revolving metal as near as possible to it. Now set a bell glass on the pane of glass; the former must contain a pretty strongly magnetized steel bar *n s*, suspended by a silk thread; this magnet should be made to rise or fall at pleasure by means of a roller *r*. The intensity of the action which the revolving disc of metal exerts on the bar magnet, the velocities being equal, is greatest when the magnet is nearest to the glass plate, and it decreases in proportion as its distance is increased by winding up the roller.

Fig. 254.



Dr. Böttger advises that instead of a common bipolar magnet we should use one whose two ends are equal and similar poles. Magnets of this kind are almost indifferent to the influence of terrestrial magnetism, and are equally as strongly magnetic, which last circumstance is of considerable importance to ensure the successful performance of these experiments in rotating magnetism. One of these tripolar magnets will instantly follow the copper plate, even if the latter revolve with but a moderate velocity. We have already stated in § 454. and § 567. how these astatic needles may be easily made; it is worthy of remark that those made in the latter of these ways by means of the electric current are generally more powerful and more completely neutralized.

Second Expt. Instead of the copper disc, now place a powerful horse-shoe magnet on the axis of the whirling table with its arms upwards, and suspend a copper disc in the bell glass instead of the magnet, as in the first experiment: on causing the horse-shoe to revolve, the copper plate will turn round also.

In both these experiments the intensity of the action will be affected by substituting plates of some other metal instead of copper. Babbage and Herschel have in a twofold manner investigated the different degrees of magnetic excitability in various metals. Assuming that of copper = 1, the results were by one mode

Copper	= 1·00
Zinc	= 0·90
Tin	= 0·47
Lead	= 0·25
Antimony	= 0·11
Bismuth	= 0·01

and by the other

Zinc	= 1·11
Copper	= 1·00
Tin	= 0·51
Lead	= 0·25
Antimony	= 0·01

With regard to the other metals, silver seemed to hold a high rank in the series, and gold but a low place; mercury, with respect to its magnetic force, stood between antimony and bismuth.

Non-metallic substances exerted but little influence, and metallic plates when broken, were far less powerful than when whole.

Screens of non-magnetizable substances, *i.e.* such as could not be rendered magnetic in the same way as iron and steel, excited no influence whatever.

Every revolving metal disc exerts a repulsive influence on the N. and S. poles of a bar magnet suspended above it. This may be shown in the following manner:

Third Expt. Hang a magnet vertically from one arm of a balance, counterpoise it by a weight at the other arm. When thus balanced, place the magnet above a copper plate that is revolving rapidly, and the arm of the balance will fly up whichever pole may happen to be lowermost.

Every metal disc in a state of rotation has a circle of indifference, over which if a magnet be suspended vertically its position will not vary, but if it be hung within this circle, it will be attracted towards the centre, if without it, will be repelled from it. This may be proved by the following experiment.

Fourth Expt. Procure a dipping needle which may be made to stand vertically, either by loading its north pole, or by bringing its axis of rotation in the magnetic meridian; place it above a revolving copper plate, so that its motion may follow in the direction of the radius of the disc, and the following effects will be observable:

a.) If the north pole stand above the centre of the disc, the needle will remain at rest.

b.) Move it back a little beyond the centre and till it arrives at the circle of indifference, it will be deflected towards the centre.

c.) On coming over the circle of indifference it again becomes vertical.

d.) If carried beyond this circle it inclines towards the circumference of the disc.

Instead of a dipping needle, a strongly magnetized sewing or knitting needle may be used, which must be suspended by a fine thread above the plate in the different positions that have been just described.

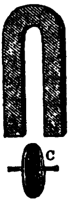
Arago endeavoured to account in the following manner for the three different motions which a revolving metal disc generates in a magnet, by supposing that its influence was exerted in a three-fold direction, viz., at right angles to the radius of the disc, or tangentially to the direction in which it revolves; secondly, at right angles to the plane of the disc, and thirdly, in the direction of its radius, *i. e.* in opposite directions from the point of indifference in each of its semi-diameters. The revolving motion of the magnet or disc answers to the first, the repulsion of the magnet's poles from the rotating metallic surface to the second, and the opposite tendencies of the dipping-needle from the revolving disc's circle of indifference are owing to the third.

§ 584.

As these phenomena were observed prior to the discovery that electric currents might be generated by magnets, it was at first attempted to account for their existence by referring them to the ordinary inductive influence of magnetism. Faraday recognized the true cause of all these phenomena in the electric currents produced by magnetism, and succeeded in experimentally verifying the accuracy of his supposition by proving the existence of such magneto-electric currents in a plate of copper which he made to revolve in proximity to the pole of a powerful magnet.

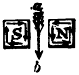
The following are the experiments:

Fig. 255.



First Expt. He made a copper disc C, *fig.* 255. to revolve about a horizontal axis between the poles SN of a powerful horse-shoe magnet, so that its upper edge coincided with the plane of the polar surfaces, as is represented in the *fig.*, or he even allowed the edge to project a little within the magnet: one wire of a delicate galvanometer was then put in contact with the amalgamated edge of the copper disc, and the other with its metallic axis; then when the disc was made to revolve, the galvanometer needle was deflected; the side to which it was deflected depending on the direction in which the disc was turned. When made to revolve one way, the needle showed a current which flowed from the centre of the disc to its upper edge, when turned the other way the current ran from the edge to the centre.

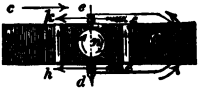
Fig. 255 a.



Both directions answered to the laws of magnetic induction, § 575., as may be perceived from *fig.* 255 *a.* For let the squares S and N represent the poles of a horse-shoe magnet and the arrows in them the course of the currents according to Ampère's hypothesis; it is clear that these currents have the same direction at the contiguous sides of their poles and consequently at the sides which in the experiment just described are next the disc. Now let the disc revolve so that its upper edge shall be in the same direction with these currents, *i. e.* in the direction of the arrow *a b*, and the galvanometer will indicate a current proceeding from the centre of the disc towards its edge; but if the rotation were reversed the needle's deflection would show that the current went from the edge to the centre.

Next, break the connexion of the disc with the galvanometer, and the induced currents will necessarily complete their course within the disc itself, for they cannot be carried off by the wires after contact has been broken; from these currents, then, those various influences on the poles of the magnet are derived which generated this inductive action.

Fig. 256.



Second Expt. After Faraday had, by means of the first experiment, established the production of induced currents under the operation of the above-named influence, he took a rectilinear slip of copper *a b* *fig.* 256., amalgamated its edges, on which he laid the copper cylinder *e d*, likewise amalgamated, which was connected with the galvanometer *g*, and so formed the circuit *e g d*: on this strip of copper he placed the north pole *n* of a powerful magnet, and moved the strip under it, as from *a* towards *b*. This pole then excited in the conductor a current running, as the galvanometer showed, from *n* over *d* to *g* and *e*, a course strictly agreeable to the laws of induction. Observe the currents existing in this pole according to Ampère's theory, as they are represented by the arrows in the *fig.*, and in each constituent part of the strip *a b*, which approaches the pole, *ex. gr.*, in *e f* a current will be generated from *e* to *f*, because the part *e s* of the current will act more powerfully than the part *w n*. Now if this portion come under the pole, that is, if it be situated like $e\,d$, it will recede from the current $e\,s$ and will be brought nearer to $n\,w$; both will therefore act inductively in the same direction and hereby produce a more powerful current in the direction from c to d. Again, if $e\,f$ move farther, *i. e.* come into the position of $h\,k$, it will be farther from the current $w\,e$, and consequently the current must now flow again from h to k. If in this experiment the strip of copper be moved in the contrary direction, or if the north pole be substituted for the south, the currents will flow in the opposite direction to that given in the *fig.*

Agreeably to this experiment, and in accordance with the law of magneto-electric induction, a bar magnet standing vertically above a rotating metal disc and in its centre, cannot excite any current in the latter, because in such a position of the magnet with regard to the disc, the latter can neither approach towards nor recede from the former. But so soon as the pole of the magnet is moved beyond the centre of the disc it will induce a current in the latter, which will flow in an opposite direction to the current Ampère supposes to exist in the magnet at those parts of the disc which *approach* the pole, and in the same direction with this hypothetical current in those parts which *recede* from the pole. Hence between the magnet and the parts of the disc which approach it repulsion predominates, whilst between it and the parts which recede attraction prevails, and on the resultant of these two forces the tangential, the perpendicular, and the radial action of the disc depend.

If there be but one pole above the disc of metal, as happens when a bar magnet stands vertically over it, then the latter is affected by the two opposite systems of currents in such a manner that it is repelled by those which approach and it is attracted by those which recede from it; the repulsion consequently predominates over the attraction, and accordingly the pole recedes from the disc.

Fig. 257.

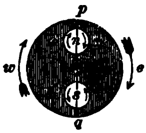
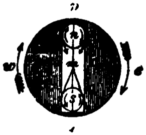


Fig. 257. will render this more intelligible. Let the larger circle represent the disc of copper revolving in the direction of the arrows, w and e; let n be the north pole of a magnet, then the part $a\,b$ of the disc corresponds with the strip of copper in Faraday's second experiment, and the current generated under the pole in the disc by the first experiment will go from the centre to the circumference, *i. e.* from m to p. But if the south pole, s, stand above the plate and $a'b'$ is the direction in which it revolves beneath it, then the induced current $q\,m$ proceeds from the periphery to the centre. According to the rotation represented in the *fig.*, the current *m p* approaches that part of the magnet's current which it repels, and recedes from that which it attracts; repulsion consequently exceeds attraction. The same is true also of the current *q m* at the magnet's south pole, whence at both poles there will be a repulsion of the disc.

Fig. 258.



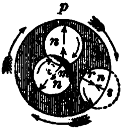
If a bar magnet be suspended horizontally above a rotating metal plate the two systems of electric currents generated by the poles both in the approximating and in the receding portion of the disc, tend to move the magnet in one direction, as is shown by the arrows in *fig.* 258.; hence results the tangential influence which drives the magnet in the direction in which the plate is turning.

This case may also be simply explained by reference to the law by which a current flowing under a magnetic needle repels it (§ 546.). In *fig.* 258. let the larger circle represent the copper disc revolving in the direction of the arrows *w* and *e*, then we shall have under the north pole *n* a current running from the centre to the circumference, *i. e.*, from *m* to *p*; under the south pole *s*, on the contrary, we have a similar one from *q* to *m*, — in other words, from the circumference to the centre. Both currents combined flow then, with this rotation of the disc, from the south pole to the north pole, under the magnet; both poles will consequently be repelled by these currents in the same direction as that in which the rotation itself obtains (compare § 546. 1.). In like manner the motion of the magnet may be explained if the copper plate be made to turn in the contrary direction.

Lastly, conceive the pole of a dipping-needle to stand vertically over some point of the rotating disc, so that it can move only in the direction of a radius of the disc; describe a circle to represent the sphere of the pole's influence; then the result attending the action of these electric currents will vary according as this circle falls within the revolving disc or projects beyond it, and according as it includes within itself the centre of the disc or not. If the circle fall entirely within the disc, while the centre of the disc lies without the circle, then the pole will be acted on in the direction of the radius by equal and opposite forces, and the needle will consequently be at rest, for it will be over the circle of indifference, the width of which it is evident must depend on the sphere of the magnetic pole's influence. Place the pole of the magnet so near the middle of the disc that its centre shall lie within the sphere of its influence, and the needle will be deflected towards the centre, the outward influence of the electric current preponderating. Bring the pole of the magnet towards the edge of the disc, so that the circle of its influence shall fall partly beyond the disc, and the inward portions of the current will preponderate so as to cause the needle to incline towards the circumference.

Again, in *fig.* 259. let the largest circle represent the copper disc, revolving in the direction of the arrows placed outside it; let *n* be the north pole of the magnet held above it in the various positions already specified, and let the lesser circles about *n* express the spheres within which the influence of the pole is confined. The arrows in these lesser circles will mark the direction of the electric currents in the magnet. Then the plate being turned round as shown in the *fig.* (according to Faraday's fundamental experiments), the induced currents flow from the centre to the circumference beneath the pole, and both portions of the currents, *e n* and *n p*, *m n* and *n q*, *r n* and *n s*, act repulsively and in opposite directions on the pole of the magnet. Hence it is seen that in position I. the portions *e n* and *n p* of the current repel with equal intensities, and accordingly the position of the magnet's pole remains unaltered; but in position II. when the centre *m* lies within the sphere of the pole's influence, the repulsive force of the portion *n q* preponderates over that of *m n*, and the pole is consequently driven inwards. Lastly, in position III., where part of the sphere of the magnet's influence lies beyond the disc, the repulsive action of the part *r n* of the current exceeds that of *s n*, whence the needle will be deflected towards the rim of the disc.

Fig. 259.



The retarded motion of a magnet oscillating above a metallic disc, admits of a similar explanation; for when the magnet oscillates, its inductive influence generates a tendency in the disc to follow its oscillations, but as the latter is unable to obey this impulse, the currents induced in it obviously have a retarding effect on the motion of the magnet, which will accordingly come to a state of rest sooner than it otherwise would.

Since electrical currents may with facility be excited in the metals when the latter are acted on either by artificial magnets or by terrestrial magnetism, Faraday is of opinion that no motion takes place in a metal without electrical currents being excited in it, if during its change of place it be in contact with other metals either at rest or in motion, or if the velocity or the direction of its motion differ from theirs. He further inferred that electrical currents may result from the earth's rotation on its axis, and from its own proper magnetism, both in its own mass and in such bodies as lie in the magnetic meridian; he would account for the aurora borealis (§ 543.) by attributing it to discharges of electricity driven by the earth's diurnal motion towards the poles, and which endeavours thus naturally to diffuse itself over the equatorial regions.

§ 585.

An account of the various modes of exciting electrical currents may very properly be terminated by an explanation of *electrical telegraphing*, one of the most interesting applications of modern science.

In this mode of telegraphing, the electric current is used to convey our thoughts, the signals being given by the different actions of the current that is carried from station to station along insulated conductors. While the current generated by frictional electricity was the only one known, experiments on this subject, performed in the last century, were limited to the use of a discharge obtained either from a Leyden jar, or from an electrical battery, and the correspondence was carried on by the luminous phenomena elicited. This mode of telegraphing was especially defective in this, that the signals could not be made to follow in sufficiently rapid succession, and on account of the high tension of frictional electricity, it was extremely difficult to insulate the current. This last obstacle was subsequently got over by the application of the voltaic current, whose chemical effects were used as telegraphic signals, but even thus every requisite was not fulfilled. But when Oersted's splendid discovery was announced, and it was seen that feeble electric currents would produce a variety of magnetic actions, electrical telegraphing received a new impulse, and there are established in England, Germany, and America, several lines where the results are as complete as could be desired. The currents are excited either by hydro-electric batteries, or by magnetic induction (§ 578.), and rotary machines (§ 579.); the telegraphic signals are either the deflexions of magnetized needles, or the intermittent excitation of magnetism in electro-magnets, or the physiological phenomena.

The superiority of this mode of telegraphing over those which were previously in use, and in which the transmission of our thoughts depended on the velocity with which light was propagated, will be seen, if we briefly explain the principles of the latter. The signals made at any one station in *optical telegraphing*, on account of the rectilinear propagation of light, will be visible only when the light falls in right lines upon the signal boards. To extend the circle of vision, the posts must be erected on high eminences, and, on account of the earth's curvature, the distance from station to station must not be great. Thus the advantage gained by the great velocity of light will be neutralized, as much delay will be caused by the repetition of the signals at the intermediate stations, and much expense will be also incurred. A still more serious defect is, that these telegraphs are not available at all times, on account of the frequent hindrances which interfere with the light in its passage through the atmosphere. Lastly, the machinery, as a whole, by which the signals are made, is so cumbrous in its form that very great velocity cannot be attained in signaling.

In *electrical telegraphing* the signal can be sent either way; the action of the current, by which the signal is made is independent of the nature of the country, or the variations in the weather: it is therefore available at every season; the stations may be wider asunder; no expensive buildings are needed; and on account of the high velocity of electricity in good conductors, as compared with that of light (comp. § 206. and § 477.), it would be possible to telegraph with our antipodes, without any intermediate station, in rather less than 0.05 of a second of time, supposing the current to be strong enough to overcome the resistance to conduction, and to make the appointed signal. One essential and important difference between the two methods is, that the air itself served to convey the signals of the optical telegraph; we have no such universal medium for transmitting the signals of the electrical telegraph.

APPENDIX.

Vol. II. Page 143.

Professor Moser of Königsberg entertains a somewhat different opinion, as to the origin of the photographic pictures, from that expressed in the text. Since the publication of the experiments which led him to form this opinion, they have been repeated with variations by Knorre, Hunt, Karsten, Waidele, and others. The result was that Moser's observations were confirmed, but additional effects were noticed that could not be fully reconciled with the theory this professor had advanced. It may not be amiss to give a brief sketch of Moser's discoveries, and of the important inferences he deduced from them; we shall then mention the theories which have been formed by the other philosophers just named.

Moser ascertained, from a great variety of photographic experiments, that Light was not the only agent that imparted to certain substances the property of condensing the vapours of mercury and iodine on those parts of their surface which were subjected to its influence, so as to depict upon them a representation of the object from which the light was emitted; but, that the same effects were produced in the absence of any perceptible light; that images were obtained not merely when silver plates were used that had been prepared in Daguerre's method, but on many other substances; that other vaporizable bodies, besides mercury and iodine, were equally efficacious in acting on duly prepared surfaces.

The following are the principal experiments performed by him:—

A coin was laid on a clean well-polished glass plate, the latter was breathed on and the coin was removed; on breathing again on the glass the outline of the coin became visible. Breathe uniformly on a clear pane of glass, and write on it with blotting paper, pencil, or indeed with almost any material; allow the glass to dry, and, each time that it is breathed on afterwards, the writing will become visible; this experiment may be repeated for a considerable time.

Other polished substances will do equally well with glass, as Moser found by using plates of metal, stones, resin, wood, leather, &c.; it is by no means indispensable, that the surface should be polished, as the phenomenon obtained when ground glass was used.

The surfaces of liquids are also adapted for these experiments.—Hold any body over some quicksilver in a state of repose, and breathe on the other portions of the fluid, or, it will be better still, if you breathe on the mercury first, and remove the moisture lightly, by any means whatever from certain parts of the surface, and if the metal be not disturbed, the traces will be distinctly seen for days whenever the mercury is breathed on.

Immediate contact is not essential, in order to produce these appearances, either prior to breathing on the surface, or in order to remove the moisture from particular points of it. Hold a screen in which some apertures have been made, over any polished body, so that it may not touch the latter, breathe on it, and allow the moisture which is condensed to evaporate; the figure of the apertures will be renewed at every subsequent breathing.

The vapour of mercury acts in the same manner as that of water, but more powerfully. Expose a polished silver plate to this vapour without breathing on it, and a beautifully distinct image will be formed of the objects previously in actual or in proximate contact with the plate.

Moser tested in like manner the vapour of iodine, which is peculiarly interesting, because it combines chemically with the silver, whereas the mercurial vapour is merely condensed without effecting any chemical change in the substance of the silver. When a prepared silver plate was exposed to the action of the vapour of iodine, in some cases, an image of the objects that had previously been in contact with it, was indicated by a difference in the colours, but whenever the plate was exposed (as in taking the Daguerreotype pictures) to mercurial vapour, a perfectly distinct image was invariably obtained, the daylight bringing out the delineation of the objects with the utmost exactness.

From a consideration of these facts, Moser drew the following important conclusion, that *if the surface of a body be brought in contact at certain points with any other body whatever, it acquires the property of condensing all such vapours as adhere to it or with which it combines chemically, in a different manner at the points of contact, from that in which it condenses them at the other parts of its surface.* Hence then we obtain the picture of the touching body.

The most important point in these phenomena, as far at least as regards the inferences deduced from it, is this, that these pictures may be produced by contact and condensation, when all light is completely excluded. Hence he goes on to say, that *the contact of bodies, the condensation of vapour and the action of light bring about similar changes in bodies, and that those changes which are produced by the first two modes,* ARE MERELY THE EFFECT OF LIGHT WHICH IS TOO FEEBLE TO BE APPRECIABLE BY OUR ORGANS OF SIGHT. Moser's idea is that *all bodies are to be considered as self-luminous;* the light which emanates from dark bodies, he distinguishes as *invisible light.* He thus proceeds: If vapours act in the same manner as light, then although there may be no visible development of light, we must attribute the effects produced by the condensation of vapours to an unseen influence of light, *which when held in this state in the vapour may properly be spoken of as latent light, it is liberated at the moment when the vapours are condensed, and exerts an influence and produces effects resembling those of light in its ordinary condition.*

Professor Knorr of Kasan repeated Moser's experiment of obtaining facsimiles of two bodies, by placing them one on the other; and directed his attention chiefly to the remark made by the latter, that these pictures were both more distinct, and were obtained in a shorter time, when the two bodies were at different temperatures. His experiments proved, that on attaining a certain difference of temperature, which, however, varied for different bodies, *pictures might be obtained even when the vapours were not condensed.* These pictures became instantaneously visible; and, according to the methods used to produce them, they were either transient or permanent. To distinguish them from the images noticed by Moser, Knorr called them *Thermographs.* He believed that they owe their origin, not merely to the difference in the temperatures of the two bodies, but also to the heights of these temperatures; and as they are produced even when the temperatures of the bodies are both equal and constant, he regarded Professor Moser's theory of invisible light as an unnecessary assumption, considering rather that this phenomenon may serve as a demonstration of the truth of Prevost's theory of exchanges.—(§ 385. p. 172. Vol. II.)

Mr. Hunt of Falmouth, who performed the like experiments, is also of opinion that these pictures are the effect of a purely thermal influence.

Professor Karsten has published another mode by which pictures of this kind may be produced. It consists in placing two bodies in contact, and sending electrical discharges through them; breathe on them, and as the vapour is condensed the image is rendered visible. Karsten calls them *electrical pictures.* This phenomenon had, however, been previously noticed by Professor Riess. Karsten by no means admits the hypothesis of the existence of invisible light; alleging, what indeed Moser admits, that it is not to be attributed to solar light, but is to be considered as inherent to all bodies: then says he, Probably it is not light at all, but rather the exertion of a force possessed by all bodies. He attributes all these phenomena to *molecular changes; and as light, heat, and electricity are all equally efficacious in producing them, their cause is rather to be sought in the influence of cohesion than in light.*

Dr. Waidele of Vienna has also thoroughly tested the experiments and observations of Professor Moser; and on comparing his own with them he thinks he is warranted in saying, that *all the effects of invisible light may be explained by referring them to the unequal capacities of bodies for absorbing gases.*

He found that when an object was brought near to a polished disc, the effects produced depended on the circumstances in which the two bodies stood with regard to the gas they absorbed, a mutual action taking place only when they were in a different condition. Either a coating of the absorbed gases was imparted to the plate, or a portion of the gaseous atmosphere adhering to the plate was withdrawn from it by the touching body, or an exchange of the gases each had absorbed was made at their points of contact.

A liquid or a gaseous body brought into proximity with the plate, so as to touch it at certain points, produced similar effects, inasmuch as it induced a change in the gaseous atmosphere about the plate.

These changes are rendered visible by the condensation of the vapours on the plate, whilst the colouring of the condensed vapour varies according to the state of the gaseous atmosphere about the plate.

The brief comparison we have just given of the different views entertained by several distinguished men of science will show, that the important theory propounded by Professor Moser with regard to invisible and latent light has not yet received the universal sanction of the scientific world. The importance of the hypothesis, as being based on new analogies, which had been detected between light and heat, may well lead us to look for further investigation into the subject; and we may sincerely express a hope that the talented professor of Königsberg will produce some further and convincing evidence in favour of the theory he has advanced.

Vol. III., Page 83.

Mr. Grove has also made another voltaic battery, of a novel construction. It belongs to that class in which one homogeneous electromotor is in contact with two heterogeneous fluids. In this case, however, oxygen and hydrogen are made to take the place of fluids: they are connected by means of acidulated water, and a strip of platinum in each gas acts as an electromotor. The platinum immersed in the hydrogen is polarized (p. 75.), so as to bring it into a state of more positive tension than that which stands in the oxygen; the former is therefore in the same electromotive condition as if placed in concentrated nitric acid, and the latter as if in caustic potash. This battery is known as the hydro-oxygen battery.

§ 511. Page 98.

Lenz's recent investigations into the laws which regulate the generation of heat by hydro-electric currents, have led him to agree with Ohm and Vorsselman de Heer in rejecting Fechner's and Poggendorff's notion with regard to the existence of any *resistance to the transmission of the current.* They attribute all these phenomena to the polarization of the metals, and give the following as the laws they have observed: —

1.) The polarization of the electrodes (metals) happens instantaneously with its full intensity when the current begins.

2.) It is not dependent on the intensity of the current, or on the size of the electrodes (their surfaces in action?), at least, when the currents are powerful, and the electrodes of considerable dimensions.

3.) It does depend on the nature of the electrodes (metals) and on the fluid in contact with them, but not on the degree of its concentration.

If, then, we regard the polarization of the electromotors (or metals) as a diminution of the electromotive force, which may be represented by p, we must change Ohm's fundamental formula for the intensity of the current (page 101.),

$$I = \frac{E}{R+r} \quad \text{into} \quad I = \frac{E-p}{R+r}$$

Page 163.

The latest and most complete thermo-electric series is Marchand's; it may be found in his "Journal für Prakt. Chem." xxix. S. 494.

Lead-ore, amber, bismuth, nickel, English palladium, French palladium, mercury, French platinum, tin, lead, bronze, brass, gold, silver, fine silver, zinc, copper, Russian platinum, carbon, cast-iron, graphite, fusible metal, iron, arsenic, antimony.

Page 186.

Mr. Faraday's discovery that a ray of light may be electrified and magnetized, and that lines of magnetic force may be rendered luminous, is too important to be passed over. The following abridged account of the paper which he read before the Royal Society in November last, is taken from the "Athenæum" of December 6. 1845: —

Mr. F. stated that for a long time past he had felt a strong persuasion, derived from philosophical considerations, that, among the several powers of nature which, in their various forms of operation on matter, produce different classes of effects, there exists an intimate relation; that they are connected by a common origin, have a reciprocal dependence on one another, and are capable, under certain conditions, of being converted the one into the other. Already have electricity and magnetism afforded evidence of this mutual convertibility; and, on extending his views to a wider sphere, the author became convinced that these powers must have relations with light also. Until lately, his endeavours to detect these relations were unsuccessful; but at length, on instituting a more searching interrogation of nature, he arrived at the discovery recorded in the present paper, namely, that a ray of light may be electrified and magnetized, and that lines of magnetic force may be rendered luminous. The fundamental experiment revealing this new important fact, which establishes a link of connexion between two great departments of nature, is the following: — A ray of light issuing from an Argand lamp is first polarized in the horizontal plane by reflexion from a glass mirror, and then made to pass, for a certain space, through glass composed of silicated borate of lead, on its emergence from which it is viewed through a Nichols' eye-piece, capable of revolving on a horizontal axis, so as to interrupt the ray, or allow it to be transmitted alternately in the different phases of its revolution. The glass through which the ray passes, and which the author terms the dimagnetic, is placed between the two poles of a powerful electro-magnet, arranged in such a position as that the line of magnetic force resulting from their combined action shall coincide with, or differ but little from, the course of the ray in its passage through the glass. It was then found that if the eye-piece had been so turned as to render the ray invisible to the observer looking through the eye-piece before the electric current had been established, it becomes visible whenever, by the completion of the circuit, the magnetic force is in operation, but instantly becomes again invisible on the cessation of that force by the interruption of the circuit. Further investigation showed that the magnetic action caused the plane of polarization of the polarized ray to rotate, for the ray was again rendered visible by turning the eye-piece to a certain extent, and that the direction of the rotation impressed upon the ray, when the magnetic influence was issuing from the south pole and proceeding in the same direction as the polarized ray, was right-handed, or similar to that of the motion of the hands of the watch, as estimated by an observer at the eye-piece. The direction in which the rotation takes place will, of course, be reversed by reversing either the course of the ray or the poles of the magnet. Hence it follows that the polarized ray is made to rotate in the same direction as the currents of positive electricity are circulating both in the helices composing the electro-magnet, and also as the hypothetical currents, which, according to Ampère's theory, circulate in the substance of a steel magnet. The rotatory action was found to be always directly proportional to the intensity of the magnetic force, but not to that of the electric current; and also to be proportional to the length of that portion of the ray which receives the influence. The interposition of substances which occasion no disturbance of the magnetic forces, produced no change in these effects. Magnets consisting only of electric helices acted with less power than when armed with iron, and in which magnetic action was consequently more strongly developed. The author pursues the inquiry by varying, in a great number of ways, the circumstances in which this newly-discovered influence is exerted, and finds that the modifications thus introduced in the results are all explicable by reference to the general law above stated. Thus the effect is produced, though in a less degree, when the polarized ray is subjected to the action of an ordinary magnet, instead of one that derives its power from a voltaic current, and it is also weaker when a single pole only is employed. It is, on the other hand, increased by the addition of a hollow cylinder of iron placed within the helix, the polarized ray traversing its axis, being then acted upon with great energy. Helices act with equal power in any part of the cylindric space which they inclose. The heavy glass used in these experiments was found to possess, in itself, no specific magneto-inductive action. Different media differ extremely in the degree in which they are capable of exerting the rotatory power over a polarized ray of light. It is a power which has no apparent relation to the other physical properties, whether chemical or mechanical, of these bodies: yet, however it may differ in degree, it is always the same in kind; the rotation it effects is invariably in one direction, dependent, however, on the direction of the ray and of the magnetic force. In this respect it differs essentially from the rotatory power naturally possessed by many bodies, such as quartz, sugar, oil of turpentine, &c., which exhibit the phenomena of circular polarization, for in some of these the rotation takes place to the right, and in others to the left. When, therefore, such substances are employed as dimagnetics, the natural and the superinduced powers tend to produce either the same or opposite rotations, and the resulting effects are modified according as they are cumulative in the former case, and differential in the latter. In the concluding section of the paper the author enters into general considerations on the nature of the newly-discovered power of electricity and magnetism over light; and remarks that all these powers possess in common a duality of character which constitutes them a peculiar class, and affords an opening which before was wanting for the appliance of these powers to the investigation of this and other radiant agencies. The phenomena thus brought to light confirm the views entertained by the author relative to the constitution of matter as being spheres of power, for the operation of which the conception of a solid nucleus is not necessary, and leads to the presumption that the influence of magnetism on bodies which exhibit no magnetic properties, consists in producing in them a state of electric tension tending to a current; while on iron, nickel, and other bodies susceptible of magnetism, currents are actually established by the same influence.

The author stated that he was still engaged in the prosecution of these inquiries.

INDEX TO VOLS. II. AND III.

N.B. *The Roman numerals refer to the volume, and the Arabic to the page.*

A.

Aberration of light, ii. 20. Spherical aberration caused by mirrors, 31. By lenses, 58. Chromatic aberration, 83. Circle of, 84.
Absorption of light, ii. 41. 87. Of heat, 172.
Achromatic prism, ii. 85. Lenses, 86.
Aeolipile, ii. 234.
Aërial electricity, iii. 173.
Air thermometer, ii. 151.
Alcarazzas, ii. 212.
Amalgam for the rubber of an electrical machine, iii. 20. Amalgamating the zinc in a hydro-electrical battery, 80.
Ampère's electro-dynamic law, iii. 193. Electro-dynamic apparatus, 195. Solenoid, 205. Theory of magnetism, 207. Rotating apparatus, 210. 213.
Anamorphoses, catoptric, ii. 40. Dioptric, 56.
Anion, iii. 121.
Anode, iii, 121.
Aperture of lenses, ii. 58.
Armature of a natural magnet, ii. 268.
Astatic needle, ii. 285.
Athermanous, ii. 174.
Atmosphere, magnetic, ii. 272. Electrical, iii. 10.
Atmospheric engine, ii. 238. 240.
Atomic weight and specific heat, ii. 190.
Attraction, magnetic, ii. 267. Electrical, iii. 8. 17. Electrodynamical, 193. Between magnets and electric currents, 187. 206.
Axis, of a spherical mirror, ii. 30. Of a lens, 57. Of double refraction, 71. Of a magnet, 268. Magnetic of the earth, 294.

B.

Barometer-guage, ii. 221. 243.
Bath, electrical, iii. 65.
Battery, electrical, iii. 40. Voltaic, 83. Constant, 133.
Boiler, ii. 237. 242.
Boiling point, ii. 204. Of different liquids, 205. Of saline solutions, 205. Variations in, 206. On the thermometer, 148. How determined, 148.

C.

Calorimeter, ii. 186. Rumford's, 188.
Camera obscura, ii. 10. Lucida, 46.
Capacity for Heat, ii. 182.
Cathion, iii. 121.
Cathode, iii. 121.
Catoptrics, ii. 21.
Caustic curves, ii. 31.
Charge, electrical, iii. 38.
Chemical theory of electricity, iii. 147.
Coercive force:—molecular resistance, ii. 274.
Cold, produced by freezing mixtures, ii. 200. Greatest degree of artificial, 201. Natural, 202. Caused by evaporation, 211. By electrical currents, iii. 170.
Collector, electrical, iii. 50.
Coloured rings:—Newton's, ii. 94. Nobili's, iii. 137.
Colours, prismatic, ii. 73. Different refrangibility of, 73. Primary and secondary, 81. Complementary, 82. Objective, 87. Pigments, theory of, 88. Affected by interference, 93. By reflexion, 94. By diffraction, 96. By polarization, 108. Entoptic colours, 110. Subjective, 122.
Combustion, by means of electricity, iii. 61. 110.
Commutator, iii. 188.
Compass, ii. 276.
Compensation-pendulum, Harrison's, Graham's, ii. 159.
Complementary colours, ii. 82. In polarized light, 110. In accidental colours, 122. In coloured shadows, 124. By double refraction, 124.
Concave lens, ii. 56. 62.

Concave mirror, ii. 29.
Condensation of steam, ii. 215.
Condenser in a steam engine, ii. 238. 245. Electrical, ii. 49. Peclet's double, 51.
Conducting power, electrical, iii. 5. Of solids, 96. Of liquids, 97. Affected by state of aggregation, 5. 97. Laws of, 98. Thermal, of solids, ii. 178. Of liquids, 179. Of gases, 180. Application of the unequal thermal conducting power of bodies, 181.
Conduction of light,—insulation, ii. 5. Of heat, 177. Of magnetism, 270. Of electricity, iii. 5.
Conduction, resistance to, iii. 5.
Conductors of electricity, iii. 3. 5. Of heat, ii. 178.
Contact electricity,—galvanic or voltaic electricity, iii. 68. Electricity by contact of heterogeneous solids, 69. Volta's fundamental experiment, 69. Galvani's fundamental experiment, 70. Electromotive force, 70. Electricity generated by contact of solids and liquids, 72. Of liquids with liquids, 74. Polarization of the metals, 75. Difference between frictional and contact electricity, 94. Intensity of the current, on what it depends, 96. Magnitude of the electromotive force, 96. Retarding force, 96. Difference in conducting power, 67. Resistance to conduction, 97. To transmission, 98. Reduced length, 99. Total resistance in a battery, 100. Ohm's law, 100. Effects of hydro-electric currents, magnetic, 103. Luminous, 108. Thermal, 110. Application of to blasting mines, 112. Physiological, 115. Chemical, 119. Laws regulating, 120. Electro-chemistry and electro-chemical classification of bodies, 121. Faraday's laws of electrolysis, 121. Action of the electrolytes in the battery, 132. Intensity of the current, how measured, 140. Theories as to the nature and origin of electricity, 146.
Convex lens, ii. 56. 58.
Convex mirror, ii. 29.
Copper sheathing of ships, how protected, iii. 139.
Cross in polarized light, ii. 110.
Cryophorus, ii. 214.
Crystals, change in their volume caused by heat, ii. 157. Electrical, iii. 159.

D.

Daguerreotype, ii. 142.
Declination-needle, ii. 275.
Decomposition, chemical, by electricity, iii. 66. 120. 124.
Deflagrator, iii. 85.
Density of water, ii. 163. Of steam, 217.
Depolarization, electrical, iii. 133.
Dew-point, ii. 231.
Diathermanous, ii. 174.
Differential thermometer, ii. 153. Magnetic, iii. 167.
Digester, Papin's, ii. 207. 255.
Dioptrics, ii. 41.
Dip of the magnetic needle, ii. 278. Variation in, 280.
Dipping needle, ii. 279. Electrical, iii. 218.
Discharger, electrical common, and Henly's universal, iii. 44.
Dispersion of light, ii. 86.
Distillation, ii. 216.
Double refraction, ii. 67.
Dynamometer optical, ii. 138.

E.

Earth, flattened figure of, ii. 259.
Eel, electrical, iii. 184.
Electrical machine, iii. 29. Effects produced by, 34. Armstrong's hydro-electrical machine, 155. Galvano-magnetic machine, 237. Magneto-electrical, 239.
Electricity, iii. 1. Different methods of exciting, 2. By friction, *see* Frictional Electricity. By contact, *see* Contact-electricity. By heat, *see* Thermo Electricity. By electrical currents, *see* Electro-dynamics. By magnetism, *see* Magneto-Electricity. By changes in the atmosphere, *see* Aërial Electricity. By the vital process, 183. By chemical action, 151. By mechanical separation, 157. By pressure, 158. By light, 170. General effects of, 2. Intensity and quantity, 3. Conduction, 3. Conductors, non-conductors, 3. How applied, 20. Conducting power of bodies, 5. 96. Resistance to conduction, 5. 98. Theories as to the nature of electricity, 6. Positive and negative electricity, 7. Tension, 7. Laws of attraction and polarity, 8. Electric current, 9. Its velocity, 10. 49. Duration of the electric light, 48. Electricity by induction, 10. Electric telegraph, 254.
Electro-chemistry, iii. 123.
Electrode, iii. 121.
Electro-dynamics, iii. 186. Action of currents on each other, 193. Ampère's law, 193. Parallel currents, 193. Currents not parallel, 196. Rotation of electrical cur-

rents, 201. Solenoid, 205. Influence of magnets on electric currents, 206. Of a solenoid, 207. Ampère's theory of magnetism, 208. Rotatory movements by magnets and electric currents, 209. Law of the action of electric and magnetic currents, 190. 206. Influence of terrestrial magnetism on electric currents, 216. Electric dipping needle, 218. Electric variation needle, 219. Influence of the current of terrestrial electricity on magnetic needles, 220. Rotation excited by terrestrial magnetism, 221. Inductive influence of electric currents, 229. Primary and secondary currents, 229. Duration and direction of secondary currents, 229. Different effects of induced currents, 232. The extra current, 233. Induced currents caused by friction electricity, 234.
Electro-gilding, &c. iii. 133.
Electrolysis, iii. 120. Faraday's law of, 131. Theory of, 121.
Electrolyte, iii. 120.
Electro-magnet, iii. 223. Ritchie's rotating, 226.
Electro-magnetism, iii. 187. Oersted's discoveries, 187. Deflection of the needle, on what dependent, 192. Electro-magnets, 223. Laws for determining their suspensive power, 225. Great suspensive power of, 226. Ritchie's rotating electro-magnet, 226. Electro-magnetic machines, 228. Electro-magnetism applied to telegraphing, 254.
Electrometers, iii. 12. Cavallo's, Bennet's, Volta's, 13. Henley's, Brande's, Coulomb's torsion-electrometer, 14. Oerstedt's, 15. Bohnenberger's and Becquerel's, 16.
Electromotive force, iii. 70.
Electromotor, iii. 70.
Electrophorus, iii. 51,
Electroscope, iii. 12. The electrical pendulum and the electrical needle, 13.
Electrotonic, iii. 230.
Emanation theory, ii. 3.
Emissive force, ii. 169.
Expansion of bodies by heat, ii. 145. Of solids, 156. Liquids, gases, 162. Steam, 164.
Eye, structure of, ii. 111.

F.

Fata Morgana, ii. 50,
Feed-pipe, ii. 242.
Field of sight, ii. 139.
Figures, Lichtenberg's, iii. 56. Nobili's, 137.
Floating apparatus, De la Rive's electro-magnetic, iii. 194. 205. 209.
Focal distance, ii. 31. 58.
Focus of a concave mirror, ii. 31. Of a convex mirror, 39. Of a convex lens, 58. Of a concave lens, 62.
Four-way cock, ii. 245.
Fraunhofer's spectrum, ii. 76.
Freezing mixtures, ii. 200.
Freezing of water by evaporation, ii. 213.
Freezing-point, ii. 148. Of different liquids, 203.
Frictional electricity, iii. 10. Fundamental effects of, and experiments, 11. Vitreous and resinous electricity, 17. Electrical series, 19. Use of conductors and non-conductors, 20. Insulation and loss of electricity, 22. Induction of electricity, 24. Latent electricity, 26. Difference between conduction and induction, 26. Electrical machine, 29. Apparatus for increasing electrical intensity, 37–45. 49–53. Discharge of jar or battery, 44. Velocity of the electric current, 45. 47. Duration of the spark, 47. 49. Experiments; generation of motion, 54. Positive and negative electricity, 56. Luminous phenomena, 57. Phosphorescence, 58. Mechanical effects, 59. Thermal, 61. Magnetic, 64. Physiological, 65. Chemical, 66. Sources of frictional electricity, 67.
Fulgurites, iii. 178.
Fusion, point of, ii. 196. Of the metals, 196.

G.

Galvanism, see Contact-electricity.
Galvanometer, iii. 104. Jacobi's, 105. Schweigger's, 105. Nobili's 106.
Gases, capacity of, for heat, ii. 188.
Geothermometer, ii. 259.
Gold-leaf electrometer, iii. 13.
Governor, ii. 246.
Gridiron pendulum, ii. 159.

H.

Hail, iii. 179.
Hardness of steel for magnets, ii. 297.
Heat, ii. 143. Different effects of, 144. Latent and sensible, 144. Theories as to its nature, 145. 262. Causes a change in the volume of bodies, 145. Instruments for measuring, 147. Expansion of

solids, 156. Of liquids, 162. Of gases, 164. Propagation of heat, 167. By radiation, 168. Decrease in its intensity, 168. Velocity of, 169. Emission, 169. Reflexion, 170. Absorption, 172. Transmission, 174. Refrangibility, 175. Polarization, double refraction, and interference, 177. Heat propagated by conduction in solids, 178. In liquids, 179. In aëriform bodies, 180. Capacity for heat, 181. Methods of determining, 185. Relation to atomic weight, 190. Variation in the capacity, 191. Causes of, 193. Causes which induce a change in the form of aggregation, 194. Fusion or melting, 195. Solidification, 202. Ebullition, 204. Vaporization, 210. Vapours and steam compared with the permanent gases, 216. Hygrometry, 229. Application of steam, 234. Sources of heat, 255. Sun's rays, 255. Change in form of aggregation, 257. Terrestrial heat, 259. Animal heat, 261. Mechanical means, 261. Electricity, 259, iii. 61. 110. 233. 243. Light and heat compared, ii. 262.
Heights, measurement of, by thermometer, ii. 207.
Heliography, ii. 142.
High-pressure engine, ii. 239.
Horse-power, ii. 250.
Hydro-meteors, ii. 216.
Hygrometer, ii. 229. Saussure's, 230. Le Roy's 231. August's psychrometer, 232.
Hygroscopic substances, ii. 229. Peculiar application of, 233.

I.

Iceland spar, ii. 68.
Image, physicial or aërial, ii. 34. 60. Of objects on the retina, 113.
Imponderable bodies, ii. 1.
Incidence, angle of, of a ray of light, ii. 42.
Indifference, point of electrical, iii. 24. 89. Magnetic, ii. 270.
Inductive influence of electrical currents, see Electrodynamics.
Insulating stool, iii. 35.
Insulation, ii. 5.
Intensity of luminous bodies, ii. 15.
Interference of waves of heat, ii. 177. Of light, 92.
Ions, iii. 121.
Isoclinic lines, ii. 280.
Isodynamic lines, ii. 286.
Isogonic lines, ii. 277.
Isothermal lines, ii. 260.

K.

Kaleidoscope, ii. 27.
Keeper of a magnet, ii. 296. 314.
Kite, electrical, iii. 174.

L.

Leidenfrost's phenomenon, ii. 205. 244.
Leyden jar, iii. 41. Lane's, 41.
Light, ii. 3. Theories as to its nature, 3. Luminous bodies, 4. Propagation of light, 8. Theoretical explanation of, 9. Intensity of, 13. How measured, 14. Absolute intensity, 15. Velocity, 19. Reflexion, 21. Theory of, 23. Quantity of light reflected, 40. Refraction, 41. Theory of, 46. Astronomical and terrestrial refraction, 50. Double refraction, 67. Unequal refrangibility of differently coloured light, 73. Recomposition of white light, 80. 88. Absorption and decomposition, 87. Explanation of, 90. Interference, 92. Diffraction, 96. Polarization, 97. Vision, 111. Optical instruments, 125. Chemical effects of light, 139. Daguerreotype, 142. Magnetic effects of light, 139. 312. Electrical, iii. 170. Light without heat, ii. 257. Light and heat compared, 262.
Light, duration of the impression of, ii. 122.
Light, Drummond's, ii. 17.
Light, rays of, ii. 8. Coloured, 73, Chemical, 139.
Lightning conductor = paratonnere, iii. 179.
Loadstone, ii. 268.

M.

Machine, electrical, iii. 29. Cylinder, 30. Plate, 31. Rotatory, 226. 239.
Magnets, natural and artificial, ii. 266. Attraction and polarity of, 265. 275. Poles and axis, 268. Anomalous magnets, 268. Saturation, 297. Magnetic properties of steel, 297. Loads carried by magnets, 306. How to calculate, 307. Magnetic intensity, how measured, 308. Magnetic virtue, how strengthened or impaired, 314. Ampère's solenoid, iii. 205. Effect of an electric current on a magnet, 190. Oersted's discovery, 190. Influence of a magnet on an electric current, 206. Rotation, 209. Produced by electric cur-

rents, 221. Temporary or electro-magnetism, 223. Excites electric currents, 234. 246.
Magnetism, ii. 265. Transmitted through almost all bodies, 267. Like poles repel, unlike attract, 269. Conduction, 270. Induction, 271. Theory, 273. Terrestrial magnetism, 275. Formation of artificial magnets, 298. Magnetic influence of light, 312. Magnetism imparted by the electric current, iii. 221.
Magnetic needles, ii. 266. Mariner's compass, 276. Dipping-needle, 278. Astatic needle, 285.
Magneto-electricity, iii. 229. Excitation of electric currents by magnets, 234. Laws of magneto-electric induction, 236. Magnetic induction machine, 237. Magneto-electric rotating machines, 239. Currents excited by terrestrial magnetism, 244. By rotating magnetism, 245.
Magnetometer, Gauss's, ii. 289.
Magnifying glass, ii. 61.
Meridian, magnetic, ii. 275.
Metallic thermometer, ii. 155.
Microscope, single, ii. 126. Magnifying power of, 128. Compound, 129. Dioptric and catoptric, 129. Magnifying power of, 130. Solar and oxy-hydrogen microscopes, 130.
Mines, blasting of, iii. 112.
Mirage, ii. 52.
Mirrors, different kinds of, ii. 22. Plane, 24. Concave, 29. Convex, 39. Cylindrical and conical, 40.
Motion, electro-chemical, iii. 139.
Multiplier, Schweigger's, iii. 105. Fechner's thermo-electric, 161.
Myopia and presbyopia, ii. 118.

N.

Non-conductors, iii. 3.
Non-electrics, iii. 4.
Northern lights, iii. 182. Electrical, 58.

O.

Object glass, ii. 129. 132. 135.
Ohm's laws, iii. 100.
Optics, ii. 8.
Ozon, iii. 68.

P.

Papin's digester, ii. 207. 239. 255.
Parallax, angle of, ii. 121.
Paratonnere, iii. 180.
Penumbra, ii. 12.
Perkins's steam-gun, ii. 246.
Perpetual motion, electrical, iii. 92.
Phosphorescence, ii. 5.
Photography, ii. 142.
Photometer, Rumford's, ii. 14. Ritchie's, 14.
Pile, hydro-electric, iii. 75. Voltaic, 78. Dry, 91. Used as an electroscope, 17. 92. Secondary, 93. State of tension, 93.
Platinum, spongy, used as a pyrophorus, ii. 258.
Polariscope, ii. 99.
Polarity in magnets, ii. 268. Magnetic of the earth, 275. Induced by electricity, iii. 24. In electrical batteries, 89. In electrical crystals, 159.
Polarization of light, ii. 97. Perfect and imperfect, 97. Plane of polarization, 98. Plane of vibration, 99. Light polarized by reflexion, 101. By refraction, 103. Explanation of, 104. Light polarized by double refraction, 107. Colours of polarized light, 108. Entoptic chromatic figures, 110.
Polarization, electrical, iii. 75.
Polemoscope, ii. 26.
Poles, magnetic, ii. 268. Like and unlike, 269. Of the earth, 277. Of a battery, iii. 87. Of a solenoid, 205.
Prevost's theory, ii. 172.
Principal axis, ii. 72. Do. ray, 32. 57.
Prism, ii. 54. Achromatic, 86. Of Iceland spar, 106. 108, 109.
Psychrometer, ii. 232.
Pulse-glass, ii. 206.
Pyrometer, ii. 155.
Pyrophorus, ii. 258.

Q.

Quadrant electrometer, iii. 14.

R.

Radiating power, ii. 169.
Rainbow, ii. 77.
Reduction of metals by electricity, iii. 126. 133.
Reflecting telescope, ii. 131.
Reflexion of light, ii. 21. Total, 44. Of heat, 170.
Refracting telescope, ii. 131.
Refraction of light, ii. 41. Explanation of, 46. Index of, 43. Astronomical and terrestrial, 50. From parallel surfaces, 53. By prisms, 54. By multiplying glasses, 55.

By convex lenses, 57. By concave lenses, 62. Double, 67. Of coloured light, 73. Of polarized light, 103. Of rays of heat, 175.
Relative heat, ii. 183.
Repulsion caused by heat, ii. 145. Magnetic, 269. Electric, iii. 8. Electrodynamic, 194. Between magnets and electric currents, 187. 206.
Retina, ii. 113.
Rotating machine, electrical, iii. 239.
Rotation of the electric current, iii. 201. Owing to terrestrial magnetism, 221. Of an electric current about a magnet and vice versâ, 209. Of a magnet about its axis, 211. Of liquids, 203. 214. Electro-chemical, 139.

S.

Saturated condition of aqueous vapour in the atmosphere, ii. 229.
Sea, temperature of, ii. 199.
Series, electrical, iii. 19. Electromotive, 71. Thermo-electric, 161, 162.
Sextant, ii. 28.
Shadow, ii. 11. Umbra and penumbra, 12. Coloured shadows, 124.
Sight, field of, ii. 139.
Solar heat, ii. 255.
Solar light, its intensity, ii. 17. Dispersion of, 73.
Solar microscope, ii. 130.
Solenoid = electro-dynamic spiral, iii. 205. Effect of a stable current on, 205. Influence of on a moveable current, 207. May be regarded as a magnet, 207. Used as an electrical dipping needle, 219.
Solidification, ii. 202.
Spark, electric, iii. 35. Magneto-electric, 239. 243.
Specific heat, ii. 182.
Spectacles, ii. 118.
Spectrum, solar or prismatic, ii. 73. Curve of intensity of coloured rays, 77. Of chemical rays, 140. Of thermal rays, 140. 176.
Steam, ii. 216. Of maximum density, 217. Density of steam, 217. Expansive force of, 218. How measured, 218. Effect of pressure on steam, 226. Of temperature, 227. Expansion in vacuo and in vessels filled with gases, 228.
Steam-engine, ii. 236. Principal parts of, 237. Single-acting, 238. Atmospheric, 238. 240. Double-acting, 238. On the expansive principle, 238. Low-pressure and high-pressure, 239. Condensing and non-condensing, 239. Watt's single and double-acting, 240. Description of a double-acting condensing engine, 242. Perkins's steam-gun, 246. Application of different kinds of engines, 248. Useful effect of, how estimated, 250. Consumption of fuel, 253.
Steam-gauge, ii. 221. Heating by steam, 253. Cooking by, 254.
Stereoscope, ii. 115.
Stroboscopic plates, ii. 120.
Suspensive power of magnets, ii. 305. Of electro-magnets, iii. 223.

T.

Table X., Of the expansion of bodies by heat, ii. 158. XI. Of specific and relative heat, 184. XII. Of the force of steam from 24° to 343° Fahr., 223. XIII. Of the force of steam from 1 to 50 atmospheres, 225. XIV. For determining the intensity of hydro-electric currents, iii. 142. Intensity of the light imparted by the sun to the planets, ii. 13. Indices of refraction, 44. Lengths of the waves of light, 90. Indices of the expansion of gases, 165. Radiation of heat, 170. Reflection of heat, 170. Transmission of heat, 174. Conduction of, 178. Capacity of solids for, 189. Melting point, 196. 198. Latent heat, 198. Freezing point, 203. Boiling point, 205. Of water at different altitudes, 207. Latent heat of fluids, 210. Electrical conducting powers of the metals, iii. 96.
Telegraph, electrical, iii. 254.
Telescope, ii. 131. Refracting and reflecting, 131. Field of vision, distinctness of objects, magnifying power, 131. 138, 139. Astronomical telescope, 132. Terrestrial, 133. Galileo's, 134. Achromatic, 135. Dialytic, 136. Newtonian, 136. Herschel's, 137. Gregorian, 137.
Temperature, mean, of the day, month, and year, ii. 260.
Terrestrial heat, ii. 259.
Terrestrial magnetism, ii. 275. Magnetic declination, 275. Agonic and isogonic lines, 276. Magnetic points of convergence, 277. Dip of the needle, 278. Magnetic equator, 280. Isoclinic lines, 280. Magnetic poles of the earth, 281. "Vis directrix," 283. Intensity, isodynamic lines, 286. Intensity, how measured, 287. Variations in, 290. Periodical, 291. Irregular,

293. Theories respecting, 294. Terrestrial magnetism owing to thermo-electric currents in the earth, iii. 170. Effect of, on electric, currents, 216. On magnets, 219. Inductive influence of, 244.
Thaumatrope, ii. 120.
Thermal, rays, ii. 175. Spectrum, 176.
Thermo-electrical batteries, iii. 163. Piles, 165.
Thermo-electricity, iii. 158. Thermo-electric tension, 159. Current, 160. Effects of, 166. Thermo-electricity of the earth, 170. Origin of, 172.
Thermometer, ii. 147. Mercurial and spirit of wine, 147. Scales, 149. Self-registering, 151. Air, 151. Differential, 153. Magnetic, iii. 167.
Thermophone, ii. 264.
Torsion balance, electrical, iii. 15. Magnetic, ii. 307.
Tourmaline, iii. 159.
Transmission of heat, ii. 174.
Transparency, ii. 6.
Transverse magnet, ii. 302.
Trough apparatus, Oersted's, iii. 79.

U.

Undulatory theory, ii. 3.

V.

Voltameter, iii. 130.

W.

Water, importance of. in consequence of the changes in its form of aggregation, ii. 199. Decomposition of, by the electric current, iii. 67. 124.
Waves of light, length of, ii. 90.
Well's experiment on the radiation of heat from the surface of the earth, ii. 173.
Wrede's experiment for determining the velocity of radiant heat, ii. 169.

Z.

Zamboni's piles, iii. 91.

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